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UNITED STATES
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HYDRAULIC MODEL STUDIES OF GLENDO DAM OUTLET WORKS, GLENDO UNIT MISSOURI RIVER BASIN PROJECT, WYOMING

Hydraulic Laboratory Report No. Hyd-413

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
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Commissioner's Office--Denver
Division of Engineering Laboratories
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Hydraulic Structures and Equipment Section
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Subject: Hydraulic model studies of Glendo Dam Outlet Works--Glendo Unit--Missouri River Basin Project, Wyoming

INTRODUCTION

Glendo Dam, a part of the Missouri River Basin Project, is located on the North Platte River about 30 miles northwest of Guernsey, Wyoming, Figure 1. The dam is an earthfill structure approximately 2,000 feet long and rises 172 feet above the lowest foundation. Located near the right dam abutment is the spillway which has a maximum discharge capacity of 10,300 second-feet. The intake to the outlet works is located approximately 1 mile upstream from the dam embankment and by making use of a "hairpin" bend in the river, flow from the outlet works re-enters the river channel approximately 3 miles downstream from the dam, Figure 2.

The outlet works tunnel, which is circular with a diameter of 21 feet, branches approximately 2,200 feet downstream from the inlet structure and supplies water to both the powerplant and the outlet works, Figure 3. The outlet works branch further divides into three 12-foot-diameter circular conduits. Flow through the outlet works is controlled by three regulating gates, each 7 feet 3 inches wide by 7 feet 9 inches high.

The model studies discussed in this report were necessary to study the stilling basin performance and the flow conditions in the branching conduits for final operating and diversion conditions.

THE 1:24 MODEL

The model of the outlet works was built to a geometrical scale of 1:24 and included the trifurcation manifold which distributed the flow to the three high pressure slide gates, the gates, the chute and stilling

basin and a section of the outlet channel, Figures 4 and 5A. The tunnel upstream from the manifold was not modeled since this portion of the conduit flows under pressure where no hydraulic problems are anticipated. The conduit upstream from the manifold was represented by a 20-foot length of pipe 8 inches in diameter. A 4-vane flow straightener, 4 feet in length, was placed in the upstream end of the 8-inch pipe to evenly distribute the flow before entering the manifold.

The manifold and outlet pipe transitions were accurately fabricated from sheet metal to represent the prototype. However, since no detailed testing of the flow in the gates was contemplated in this study, a slide gate with a leaf not to scale was used to obtain a representative flow pattern entering the stilling basin.

A ring of four piezometers was placed in the 8-inch pipe, 1 diameter upstream from the manifold, to measure the pressure head in the outlet pipe. In addition, piezometers were placed at various points in the manifold, and in the circular and rectangular conduits immediately upstream from the gates to measure pressures in the system.

The chute and stilling basin were constructed of 3/4-inch plywood while the tail box was constructed of lumber and lined with sheet metal. The outlet channel and topography downstream from the stilling basin were formed from river sand to provide an erodible bed for erosion studies. The tail water elevation in the outlet channel was controlled by means of a tailgate at the downstream end of the tail box.

THE INVESTIGATION

General

The model was constructed primarily to study the performance of the stilling basin. However, it was the opinion of the laboratory that at least a portion of the manifold should be constructed to obtain a representative distribution of flow entering the stilling basin. Therefore, the manifold leading to the regulating gates was included in the model. The preliminary studies on the model indicated that, in addition to the investigation of the stilling basin performance, certain features of the manifold design also should be investigated to improve the flow distribution and overall hydraulic performance of the manifold.

The characteristics of the flow in the manifold were evaluated by means of velocity measurements and piezometers located at selected points in the system of conduits, bends, and transitions. Action in the

stilling basin was evaluated by means of erosion tests and visual observations of the stilling action in the basin. The erosion tests, which were especially helpful in determining the size, spacing, and location of the baffle piers, were made by operating the model for a time period equivalent to approximately 3 hours' prototype.

In general, the studies of the flow in the manifold and in the stilling basin were conducted at the same time by recording test data from both regions of flow. However, changes in the manifold arrangement affected the performance of the stilling basin and extensive studies of the stilling basin were made only after the design of the manifold was concluded. After the stilling basin studies were completed, the gates and transitions were removed to study the flow distribution and stilling action for diversion flows which will occur only while Glendo Dam is under construction.

Transition Studies

Preliminary. Initial studies on the preliminary transition between the circular conduit, 12 feet in diameter, and the rectangular conduit, 7 feet 3 inches wide by 7 feet 9 inches high, immediately upstream from the control gates showed a region of low pressures in the vertical bend immediately downstream from the transition, Figure 6. Five piezometers, located at the top, sides, and bottom of the rectangular conduit, indicated pressures from 12 to 21 feet of water below atmospheric when the gates were 100 percent open and discharging 11,200 second-feet. The pressures remained below atmospheric, although to a lesser degree, as the discharge was decreased to 6,000 second-feet with the gates 100 percent open. However, reducing the gate opening 8 to 10 percent resulted in pressures atmospheric or higher for the entire range of discharges. The fact that atmospheric or higher pressures were observed at partial gate openings indicated that the downstream gate frame with flared walls acted as a diverging tube, reducing the pressure in the conduit when the gates were fully open. At partial gate openings, the downstream frame no longer flowed full and the pressure in the conduit rose to atmospheric or higher.

From the above analysis it appeared the low pressures observed at near maximum discharges and full gate opening could be reduced either by raising the roof of the downstream gate frame to aerate the surface of the jet or by substituting parallel walls for the flared walls in the downstream frame. The latter solution was chosen for testing.

Recommended transition. In addition to the change in the walls of the downstream frame, mentioned above, the shape of the transition was altered to eliminate the hump in the invert of the conduit and provide a more gradual transition from the circular to rectangular conduit, Figure 7.

The revised transition (Transition B) was equipped with 10 piezometers and was tested with both parallel and flared walls in the downstream gate frame. With flared walls, the observed pressures in the transition for maximum discharge at 100 percent opening varied from 11 feet below atmospheric to 9 feet of water above atmospheric, Figure 7. Thus, pressures in Transition B were about 10 feet higher than those observed in the preliminary transition indicating that Transition B was the better design hydraulically. Parallel walls in the downstream frame were then tested. At full gate opening and maximum discharge, all observed pressures were above atmospheric and varied from 3 feet of water at Piezometer 4 to 26 feet at Piezometer 10.

Because pressures observed in Transition B were about 10 feet higher than those observed in the preliminary transition, Transition B is recommended for construction. In addition, it is recommended that the downstream gate frame be designed with parallel walls to further increase the pressures in the transition.

Stilling Basin Studies

Preliminary design. Tests were made initially on the preliminary design which is shown in Figures 4 and 5A. In general, the operation of the structure was unsatisfactory. At the maximum discharge of 11,200 second-feet with the gates wide open the distribution of flow in the stilling basin was poor. The right gate discharges approximately 10 percent more water than either of the other two gates, Figure 5B; the hydraulic jump appeared drowned; and the bulk of the flow remained near the floor of the basin with very little vertical distribution. When one gate was closed, the dead water downstream from the closed gate folded over the top of the jet from the adjacent gate causing a severe eddy in the basin.

Results of the erosion test at maximum discharge on the preliminary design is shown in Figure 5C. The deepest scour pocket formed at the downstream end of the left training wall where the channel eroded to elevation 4472 feet and exposed approximately 7 feet of the downstream cutoff wall.

Several exploratory tests were made using chute blocks and baffle piers, varying from 3 to 6 feet in height, on the stilling basin floor. The baffle piers helped materially in reducing the turbulence and surges in the basin. The improved stilling basin operation was evidenced by better flow distribution across the basin width and by a reduction in the depth of erosion in the channel.

The exploratory tests indicated that if the height of the chute blocks was increased and a row of baffle piers was installed in the basin, the length of the stilling basin could be shortened about 15 feet. The surface of the flow in the stilling basin was comparatively smooth and only for one- and two-gate operation did the stilling basin turbulence extend to the downstream end of the basin.

Basin 2. As a result of the tests and observations of the preliminary design, it was decided to shorten the length of the stilling basin from 87 feet 6 inches to 72 feet 6 inches, or 15 feet. The shorter basin is designated Basin 2, which except for the length is the same as the preliminary design.

From visual observations there appeared to be no significant change in the operation of the stilling basin as a result of decreasing the length of the basin.

The preliminary stilling basin contained no dividing walls between the three gates. Consequently, when one or two gates were closed severe eddies formed in the basin and the general operation of the stilling basin was poor. To improve the basin operation for one- and two-gate operation, dividing walls were placed between the three gates, Figure 8. Several walls, varying in length from 30 to 50 feet, were tested.

From visual observations it was determined that the walls should extend at least 11 feet downstream from the toe of the 12° 30' slope to eliminate the eddy in the stilling basin when one or two gates were closed. Figure 8 shows a comparison of the basin operation with dividing walls extending to the toe of the slope and 11 feet downstream from the slope when the left gate is closed. With the shorter dividing walls installed, Figure 8A, an eddy formed in the basin as indicated by the foam along the left training wall. However, no eddy formed when the dividing walls were extended 11 feet downstream, Figure 8B. Therefore, it is recommended that dividing walls, extending at least 11 feet downstream from the toe of the slope, be installed between the gates to prevent side eddies from forming when releases are made through only one or two gates.

Tests on the preliminary design showed that the jets from the gates remained near the basin floor with very little vertical flow distribution in the stilling basin. By installing baffle piers in the basin and increasing the height of the chute blocks, it was found that the vertical distribution of flow was improved and a general improvement of the stilling basin performance was noted. Based on these preliminary studies, extensive testing of various sizes and spacings of chute blocks

and baffle piers was undertaken to determine the best combination for optimum stilling basin performance. The chute blocks tested varied from 3 to 7 feet in height and from 3 to 5 feet wide; the baffle piers ranged from 5 to 8 feet in height and from 5 to 7 feet wide.

Table 1 shows the data for some of the more important chute block and baffle pier designs tested. In general, the preliminary chute blocks (3 feet high and 3 feet wide, Figure 4) were too small and the tests showed that a block 5 feet wide and 7 feet high was required to distribute the flow vertically and to adequately raise the jets off the floor of the stilling basin. When the height of the block was raised above 5 feet, it was found desirable to slope the top of the chute block upward in the downstream direction. The sloping top reduced the length of the block and, more importantly, increased the efficiency of the chute blocks by deflecting part of the jet in an upward direction.

The exploratory baffle pier tests on the preliminary design showed that 6 baffle piers, 5 feet 6 inches in height, were required to effectively distribute the flow in the stilling basin when used in combination with chute blocks up to 6 feet in height. Baffle piers higher than 5 feet 6 inches in height caused a rough water surface and considerable surging in the basin, Table 2. To determine the best location of the baffle piers in the stilling basin, pressures on the face of the piers were observed with the piers 5 to 30 feet downstream from the toe of the chute. Results of these tests, using square baffle piers 5 feet 6 inches on a side, are shown in Figure 9. The pressure on the test pier varied from a maximum of 83 feet of water at a distance of 5 feet from the chute to a minimum of 42 feet of water at 30 feet from the chute. The curves shown in Figure 9 indicate that the piers could be placed from 15 to 25 feet from the chute with moderate impact pressures on the face of the piers. With this range of distances established, the exact location of the baffle piers was determined to be 20 feet downstream from the chute by erosion tests and visual observations of the stilling basin performance.

Figures 5C and 10A and B show typical erosion patterns obtained for the more important pier designs for the maximum discharge of 11,200 second-feet. The least erosion was observed for Design 2-C, Figure 10A and Table 1. However, the erosion patterns for Designs 1-A through 4-C were obtained with the preliminary transition installed upstream from the gates. When the recommended transition was installed, the distribution of flow through each gate was changed and an entirely different erosion pattern was obtained with more scour occurring at the downstream end of the training walls. By comparing Figure 10B and C, it can be seen that the maximum depth of erosion increased from 6 feet with the preliminary transition to 11 feet when the recommended transition was

Table 1

CHUTE BLOCK AND BAFFLE PIER STUDIES

Chute blocks				Baffle piers			
Design	Width	Height	Top of block	Spacing	Design	Width	Height	Spacing
1	3'-0"	3'-0"	Horizontal	3'-0"	A		None	
2	3'-0"	4'-6"	Horizontal	3'-0"	B	6'-0"	6'-0"	6'-0"
3	4'-0"	4'-0"	Horizontal	4'-0"	C	5'-6"	5'-6"	5'-6"
4	3'-6"	6'-0"	Upward slope	3'-3"	D	5' to 7'	6' to 8'	4'-0"
5	5'-0"	7'-0"	Upward slope	6'-0"	E	6'-6"	8'-0"	5'-6"

Block and pier combination	Max depth of scour*	Basin operation
Design 1-A (Prelim)	10'-0"	Jets remained on floor of basin. Rough operation.
1-B	--	Considerable surging in basin. Piers appeared too high.
2-B	--	Basin operation similar to Design 1-B.
2-C	3'-6"	Scour negligible. Rough basin operation.
3-C	4'-0"	Improved basin performance but surges prevalent.
4-C	6'-0"	Smoother water surface except for Q of 5,000 and 10,000 cfs.
4-C	11'-0"	Excessive scour due to redistribution of flow resulting from recommended transition.
5-D	--	Extensive study of various sizes of blocks and piers. 5' x 7' chute blocks and 6'-6" x 8' baffle pier gave best operation.
5-E (Rec)	5'-5"	Smooth water surface for all discharges. Flow well distributed. Maximum depth of scour was 3'-0" for Q of 10,000 cfs.

*Discharge = 11,200 cfs.

installed. The change in transition designs, with the attendant redistribution of flow through the gates, necessitated further studies with chute blocks and baffle piers. Results of these additional studies showed that chute blocks 5 feet wide and 7 feet high and baffle piers 6 feet 6 inches wide and 8 feet high were required for adequate stilling basin performance and minimum erosion. Although the maximum depth of scour occurring at the downstream ends of the training walls was greater than the depth of scour observed with Design 2-C, the total material eroded was less using Design 5-E than Design 2-C. Also, the maximum depth of scour was only 3 feet when the discharge was reduced to 10,000 second-feet. Therefore, Design 5-E is recommended.

It is planned to place riprap, 3 feet in thickness, in the outlet channel for a distance of 65 feet downstream from the stilling basin, Figure 3. Erosion tests were made with a layer of gravel, having a maximum nominal diameter of 1-1/2 inches (or 36 inches prototype), placed in the outlet channel to represent the riprap. After operating the model at maximum discharge for a period of time equivalent to 30 hours' prototype, there was no appreciable movement of the riprap.

Erosion studies were made with two sizes of end sills, 3 and 5 feet in height. The erosion patterns were practically the same for each of the sills. Therefore, the preliminary end sill, 3 feet in height, is recommended for construction.

The preliminary basin design included training walls with divergence of 8° extending 14 feet 6 inches downstream from the gates, Figure 4. With the flared downstream gate frame, the distribution of flow was very good and the jets followed the diverging training walls, Figure 5. When the flared walls in the downstream gate frame were replaced with parallel walls, the model was first operated without diverging training walls downstream from the gate frame. Under this condition, reverse flow from the stilling basin backed up along the sides of the jets and caused considerable splash and a pulsating action to occur where the jet and the reverse flow met.

To improve these undesirable flow conditions, training walls with an 8° divergence and similar to the preliminary design, Figure 4, were installed in the model. Although the flow did not follow the diverging training walls, the walls prevented the reverse flow from intercepting the jets and noticeably reduced the amount of splash.

In a discussion with the designers, it was decided to continue the parallel walls downstream to a vertical line 1 foot downstream from the top of the gate frame, Figure 11. By thus extending the parallel walls, costly warped walls are eliminated. The above training wall

arrangement, which is recommended, was not tested in the model. However, because the degree of divergence is increased only from 8° to 10°, it is believed the recommended diverging walls will perform equally as well as the walls tested in the model.

RECOMMENDED DESIGN

The recommended design for the outlet works, evolved from the model studies, is shown in Figure 11. This design includes the transition, shown in Figure 7, downstream gate frame with parallel walls, chute blocks 5 feet wide and 7 feet high, baffle piers 6 feet 6 inches wide and 8 feet high, dividing walls separating the flow into 3 bays, and Basin 2 with a length of 72 feet 6 inches. Figures 12 and 13 show in more detail the transition, diverging walls, and stilling basin developed from the study.

Figures 14 through 16 show the operation of the recommended design for maximum discharge through one, two, or three gates. In general, the best stilling basin performance occurs when releases are made through three gates opened an equal amount. Under these conditions, the distribution of flow is more uniform and the full width of stilling basin is utilized. The poorest operation was observed when only one gate is operating, Figure 16. The flow is rough and concentrated in a portion of the basin. Boils extending into the outlet channel are prevalent. Therefore, only under emergency conditions should large releases be made through one gate.

Considerable data was obtained from the model to evaluate the recommended design and to provide a comparison with data obtained later from the prototype structure.

Pressures

Chute blocks. A test chute block was equipped with eight piezometers and placed in the center of the right bay. The location of the piezometers on the test block and the pressures observed for a range of discharges through one, two, and three gates are shown in Figure 17. With three gates discharging in the range of flows of 10,000 to 11,200 second-feet, the observed pressures on the test block were approximately atmospheric or higher. The maximum observed pressure was 16 feet of water above atmospheric at Piezometer 1 and the lowest pressure for three-gate operation was 1 foot below atmospheric observed at Piezometers 7 and 8.

With the center gate closed and the right and left gates discharging 8,600 second-feet, the pressures observed on the chute block ranged from 11 feet of water above atmospheric at Piezometer 1 to 5 feet below atmospheric at Piezometer 8.

The lowest pressures on the test block were observed when the center and left gate were closed and the right gate was discharging the maximum flow of 4,600 second-feet; a pressure of 13 feet below atmospheric was recorded at Piezometer 8. With a normal discharge of 3,800 second-feet through the right gate the pressures increased 1 to 6 feet; the lowest pressure, 10 feet of water below atmospheric, was again observed at Piezometer 8.

All the observed pressures were above the cavitation range. Because negative pressures were observed only for one- and two-gate operation, an emergency operating condition, it is believed the chute blocks are adequately designed against cavitation.

Baffle piers. Pressure data for operating conditions similar to those used in the chute block tests were also observed on the baffle piers. Figure 18 shows the location of the 12 piezometers on the test pier and the observed pressures for different operating conditions. The test pier was located in the right bay and to the left of the center line.

The maximum pressures were observed at Piezometer 1 on the face of the pier and varied from 40 to 71 feet of water above atmospheric depending on the operating condition. The lowest pressures, varying from approximately atmospheric pressure to 20 feet below atmospheric, were observed on the side of the pier at Piezometer 2. However, the extreme low pressure of minus 20 feet was observed only when the maximum discharge of 4,750 second-feet was released through the right gate; for two- and three-gate operation at maximum flows, the observed pressures were approximately atmospheric or higher. Therefore, except for maximum flow through one gate, no adverse pressures are expected on the baffle piers.

Right training wall. A check was also made of the pressures along the right training wall immediately downstream from the right chute block. Pressures were observed at points 2, 4, and 6 feet above the basin floor. The following table lists the pressures in feet of water observed for different gate combinations at maximum flow:

Piezometer No.	Elevation of piezometer	Number of gates operating and discharge in second-feet			
		3	3	2	1
		11,200	10,000	8,800	4,750
1	4485	6.5	4.5	10.0	8.0
2	4483	12.5	9.0	12.0	9.5
3	4481	16.0	10.5	13.5	10.0

For all operating conditions the pressures were well above atmospheric.

Jump-sweepout Data

To determine the adequacy of the depth of the stilling basin, jump-sweepout curves for one-, two-, and three-gate operation were obtained from the model. "Jump-sweepout" in this study is defined as the tail water elevation at which the entering flow ceased to flow through the stilling pool but was deflected upward at the baffle piers. Although the water surface is rough with the flow deflected upward, a pool remains in the stilling basin and the structure could operate under sweepout conditions for short periods of time without endangering the structure or causing excessive scour. However, pressures on the chute blocks and baffle piers would no doubt reach the cavitation range.

Figure 19 shows the results of these tests, in the form of curves, along with the normal tail water curve. The jump will remain in the basin for tail water elevations 1 to 5 feet below normal when two or more gates are operating. With only the right gate operating, the jump will sweep out for discharges above 4,250 second-feet; will not sweep out for lesser flows. Performance with the jump swept out is shown in Figure 16A. The maximum discharge of 4,700 second-feet may be released through either the center or left gate without the jump sweeping out at normal tail water, Figures 16B and C.

The sweepout curves emphasize the need for using all three gates when releasing flows through the outlet works. In the range of discharges from 3,000 to 8,000 second-feet, releases can be made through three gates with the tail water 1 to 4 feet lower than similar releases through one or two gates without the jump sweeping out.

Water Surface Profiles

Water surface profiles for near maximum discharges through one, two, and three gates are shown in Figures 20 and 21. The profiles were measured along the right training wall with the tail water at normal elevation, Figure 19.

Head-discharge Curves

The head-discharge relationships for flows using all possible gate combinations are shown in Figure 22. The pressure head (ordinate of Figure 22) was measured at a piezometer ring placed in the model supply pipe at Station 29+18 where the diameter of the converging manifold is 16 feet. Prior to calibrating the gates, a reinforcing post was placed in each of the Y-branches. The post was 9 inches in diameter in the upstream branch and 6 inches in diameter in the downstream branch.

The maximum discharge through the three gates for maximum reservoir elevation was determined to be approximately 12,500 second-feet. For two-gate operation, the maximum discharge was 8,100 second-feet through the right and center gates and approximately 8,600 second-feet through the other two-gate combinations. With one gate operating at maximum reservoir, the maximum discharge was found to be approximately 4,500 second-feet for each of the gates.

To determine the distribution of flow through the manifold, velocity measurements using a pitot tube were made in the rectangular conduit immediately upstream from the gates. Using the measured velocities to determine discharges, it was found that the right, center, and left gates, respectively, were discharging 35.5, 33.7, and 30.8 percent of the maximum flow.

The manifold, as tested in the model, converged from a diameter of 21 feet at the center of the Y-branch in the main tunnel (27 feet downstream from the center line of the surge tank or Station 28+80) to a diameter of 12 feet at the P.C. of the manifold bend, Figure 23. After the gates were calibrated and the model was modified for diversion studies, the designers changed the manifold design by making the manifold section a constant diameter of 21 feet to the upstream lateral where the manifold lateral converges uniformly to a diameter of 12 feet at the P.C. of the bend, Figure 23. Also, two reinforcing posts were placed in each Y-branch of the prototype instead of one post as tested in the model. Thus, the manifold losses and the distribution of flow through the three outlets in the model were probably different from those in the prototype. Therefore, some difference in the curves shown in Figure 22 and those obtained in the prototype are to be expected.

DIVERSION STUDIES

After the outlet works studies were completed, the outlet pipe transitions and slide gates were removed from the model to study the flow conditions to be expected during the diversion period. Except for the second stage concrete, shown in Figure 12, the outlet works stilling basin will be completed prior to diverting the river flow through the outlets. Figure 24A shows the arrangement of the model for the diversion studies.

Preliminary tests with diversion flows showed the operation of the stilling basin to be very poor. Proportionately more of the flow was concentrated in the right and left branches of the outlet works; at maximum discharge of 10,000 second-feet, little stilling action took place because the flow passed over the pool surface and failed to penetrate the stilling pool, Figure 24B. The amount of flow through each of the outlets was erratic, depending on whether the left conduit flowed full or partially full, Figure 24B. The right outlet always flowed full at near maximum discharges while the center outlet always flowed partially full and the left outlet flowed full or partially full, depending on the tail water elevation. Once the left outlet flowed full it continued to flow full even for below normal tail water elevations.

This erratic flow had a pronounced effect on the pressures in the manifold, Figure 25A. When the left outlet flowed full, the pressures at Piezometers 7 and 8 in the left branch dropped to a minimum of 24 feet below atmospheric. The pressures rose 15 to 24 feet when the left outlet flowed partially full.

Visual observations of the flow entering the stilling basin indicated that more flow was discharging from the right outlet than from either the center or left outlets, Figure 24B. To distribute the flow more evenly and to induce the flow to penetrate the stilling pool, a constriction was placed at the end of the right outlet, Figure 25. The constriction was a flat plate covering the upper 3-foot segment of the outlet. The constriction distributed the flow more equally between the three outlets, but at times the flow from the left outlet did not penetrate the pool. The lowest pressure, 15 feet below atmospheric, was observed in the left branch when the left outlet was flowing full, Figure 25B.

Constrictions then were placed on both the right and left outlets to further improve the stilling basin performance, Figure 26. The constrictions made the basin more effective by directing the flow so that it penetrated the stilling pool, Figure 26A. Although the right outlet was passing more flow than either of the other outlets, the

stilling basin adequately handled the maximum discharge of 10,000 second-feet. Slightly improved pressures were observed in the left branch where a minimum pressure of 11 feet below atmospheric was recorded at Piezometers 7 and 8 when all outlets were flowing full at maximum discharge, Figure 25C.

The results of erosion tests with and without constrictions on the outlets are shown in Figure 26B and C. With no constrictions on the outlets, a considerable amount of riprap, especially downstream from the right outlet, was moved in the outlet channel. With the constrictions installed the riprap remained in-place.

Since the constrictions on the right and left outlets improved the stilling basin performance, increased the low pressures in the manifold, and moved less riprap in the outlet channel, it is recommended that constrictions as shown in Figure 25 be placed on the right and left outlets.

The pressures at Piezometer 1 in Figure 25 are plotted in Figure 27 to show the pressure head required to pass various discharges for the designs tested. These curves give further evidence of the improvement obtained in the recommended design. For the preliminary design, the pressure head required to pass 10,000 second-feet varies from 2 to 20 feet depending on whether the left outlet flows full or partially full. With the constriction over the right outlet, approximately the same pressure head was required. Similarly, with the recommended design (constrictions over right and left outlets) the pressure head varied only between 9 and 12 feet. Thus, a more stable flow was indicated when constrictions are placed over both outlets.

Figure 28 shows the operation of the stilling basin for discharges of 5,000, 7,500, and 10,000 second-feet with the recommended constrictions on the right and left outlets.

It should be noted that the diversion studies were made with a manifold of smaller diameter than that of the manifold shown in the specifications (see page 12). The smaller manifold, as tested in the model, was more conducive to low pressures because of the higher velocities in the manifold section. Therefore, the specification manifold is expected to give improved performance of the stilling basin and to increase the pressures in the low pressure regions observed in the diversion model studies.

FIGURE 1
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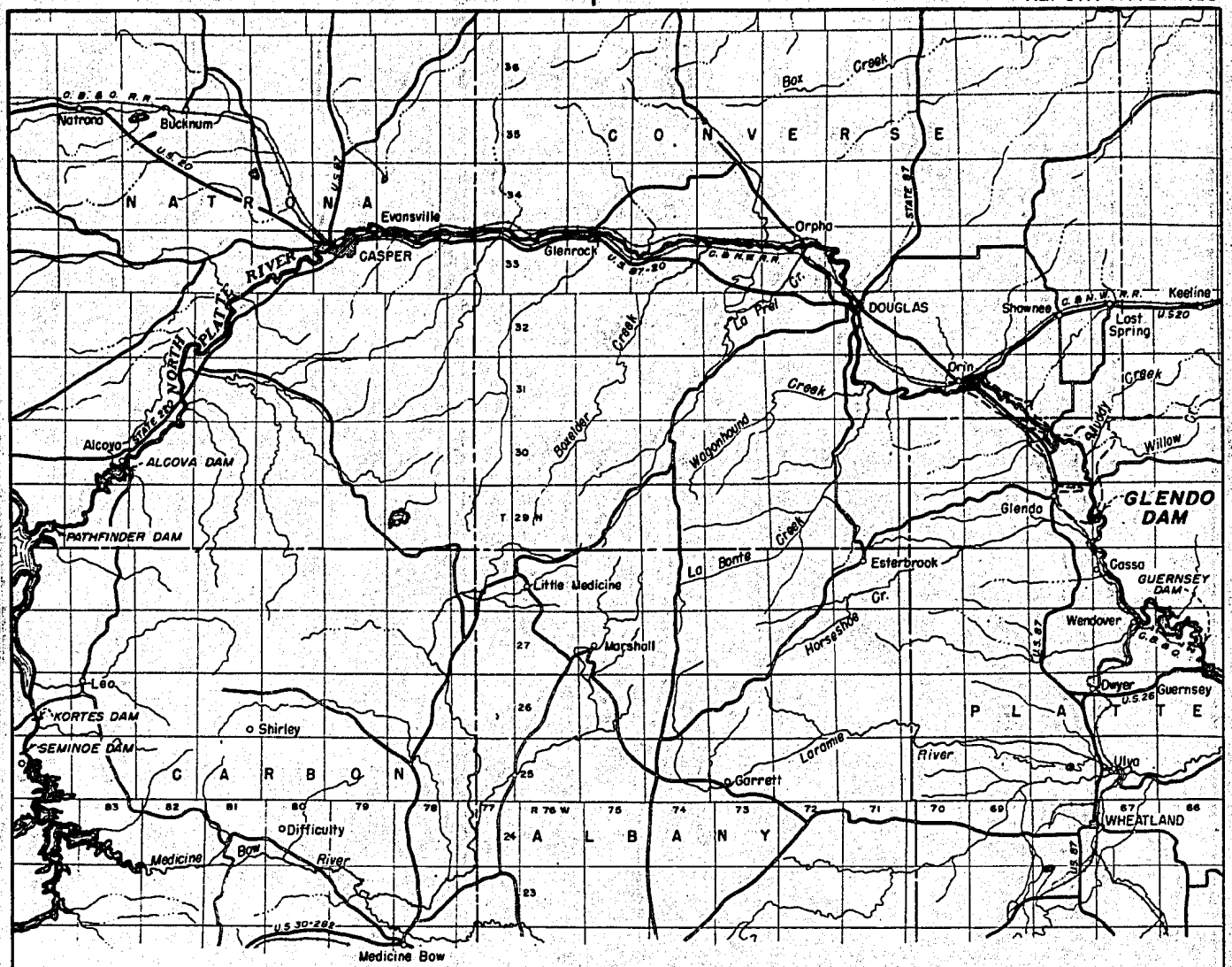
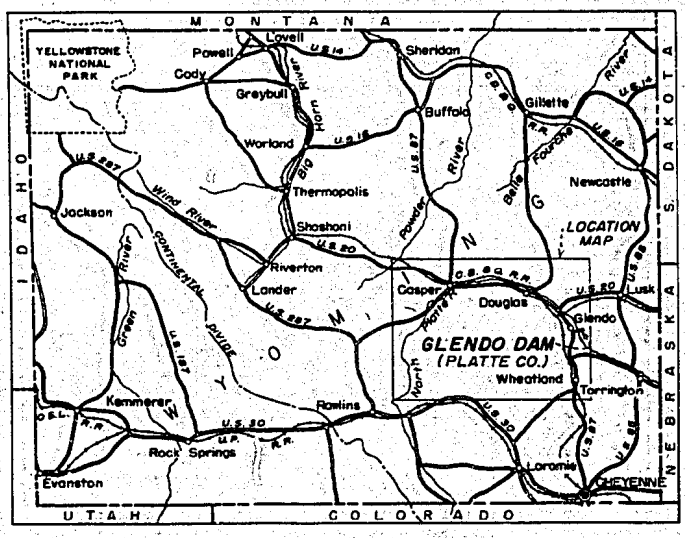
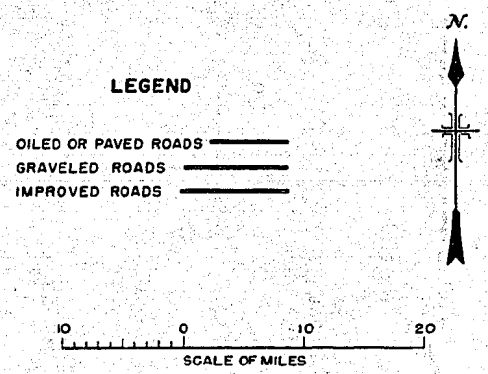




KEY MAP



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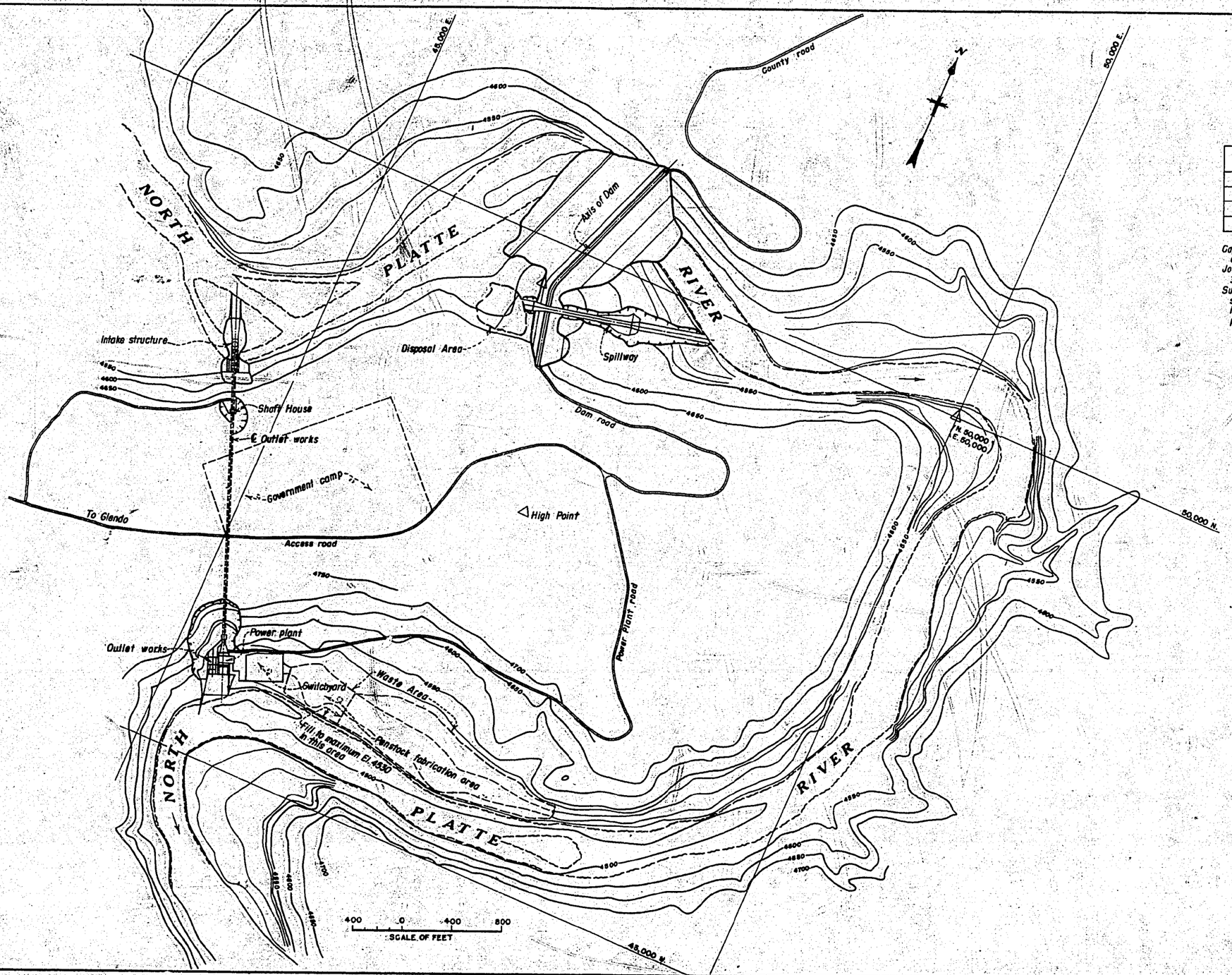
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION - GLENDO UNIT - WYO.

GLENDO DAM

LOCATION MAP

DRAWN R.B.R.-E.C.P. SUBMITTED J.J. Hammond
TRACED W.J.O. RECOMMENDED T.W.B. Keener
CHECKED [illegible] APPROVED L.N. McClellan
CHIEF ENGINEER
DENVER, COLORADO, AUG. 30, 1954 449-D-110



RESERVOIR STORAGE ALLOCATIONS

PURPOSE	ELEVATIONS	STORAGE ACRE - FEET
Flood Control	4635 to 4653	275,000
Joint Use	4545 to 4635	512,000
Dead Storage	Streambed to 4545	13,000
Total Storage Capacity		800,000

Capacity of 525,000 A.F. between streambed (El. 4500) and elevation 4635 includes an allowance of 115,000 A.F. for sediment
Joint use storage includes 100,000 A.F. for irrigation and 310,000 A.F. for power.
Surcharge of 328,600 A.F. (Max. W.S. El. 4669) in combination with spillway capacity of 10,335 cfs. and outlet capacity of 11,200 cfs. is provided to protect against the inflow design flood having a peak of 180,000 cfs. and 15 day volume of 849,000 A.F.

6-5-56 D	REVISED SHAFT HOUSE ACCESS ROAD
3-10-58 D E.E.P.	CHANGED INFLOW DESIGN FLOOD
10-8-58 D E.E.P.	OUTLINED WASTE AND PENSTOCK FABRICATION AREA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION-GLENDO UNIT-WYO.

GLENDO DAM
GENERAL PLAN

DRAWN E.S.P. SUBMITTED
TRACED N.R.W. RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER

DENVER, COLORADO, AUG 30, 1954 | 449-D-121

FIGURE 3
REPORT HYD. 413

SECTION G-G

SECTION E-E

PLAN

SCALE OF FEET

DETAIL X

SECTION F-F

PART SECTION THRU ℄ TUNNEL
PIPING ARRANGEMENT FOR GROUTING BEHIND STEEL LINING

WROUGHT IRON WATER STOP

DISCHARGE CURVES

SECTION A-A

SECTION B-B

SECTION C-C

DETAIL Z
GROUT AND VENT OUTLET

SECTION D-D
TYPICAL – STA. 26+60 TO STA. 28+23

STEEL LINER PLATES

STEEL RIBS

STEEL RIBS WITH LAGGING

ROOF SUPPORT BOLTS

STEEL RIBS WITH LINER PLATES

TUNNEL SUPPORT DETAILS

NOTES

Spacing of transverse construction joints in tunnel not to be greater than 50'.

Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days, except that manifold anchor block concrete shall attain 3000 lb. compressive strength in 90 days.

The following items not shown: reinforcement, trashracks, electrical conduits and apparatus, ventilating system, reservoir level gage piping, miscellaneous piping, drains and metalwork.

Concrete finishes in tunnel to be F2 for formed surfaces and U2 for untormed surfaces.

(WAFA) Designates second stage concrete.

Wrought iron waterstops will be placed in all transverse construction joints in tunnel lining.

6-14-55 D CAW	CHANGED INLET AND DISCHARGE CURVE.
8-29-55 D CAW	TRACED ADDED GROUTING DETAILS.
2-23-55 D C.A.W.	CHANGED CONTRACTION JOINT TO CONSTRUCTION JOINT.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION – GLENDO UNIT – WYOMING

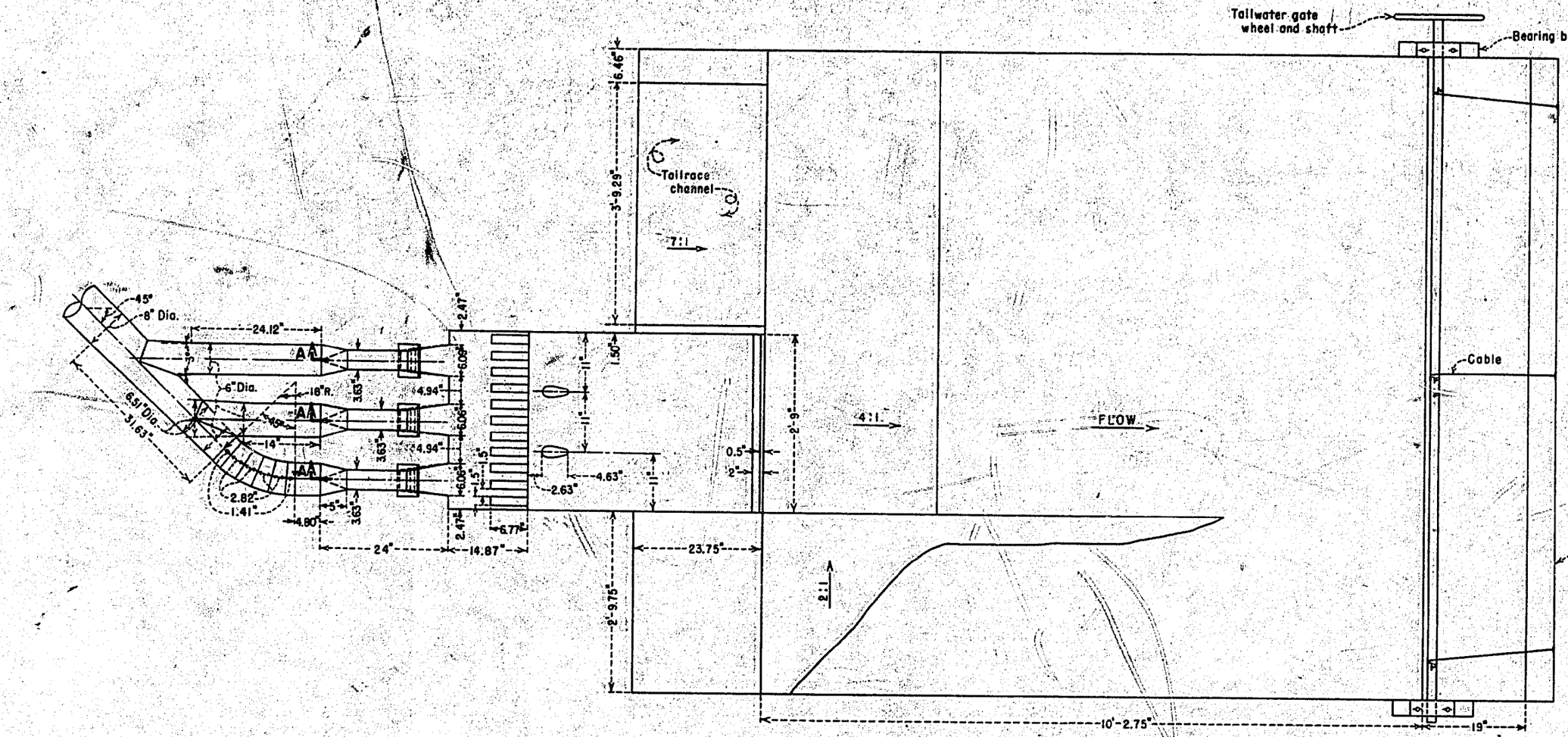
GLENDO DAM
OUTLET WORKS
PLAN AND SECTIONS

DRAWN	H.A.N.	SUBMITTED	H.W. Tabor
TRACED	R.V.S.	RECOMMENDED	J.J. Hammond
CHECKED	C.A.W.	APPROVED	K.B. Keener, CHIEF DESIGNING ENGINEER

DENVER, COLORADO, MAR. 15, 1954

449-D-59

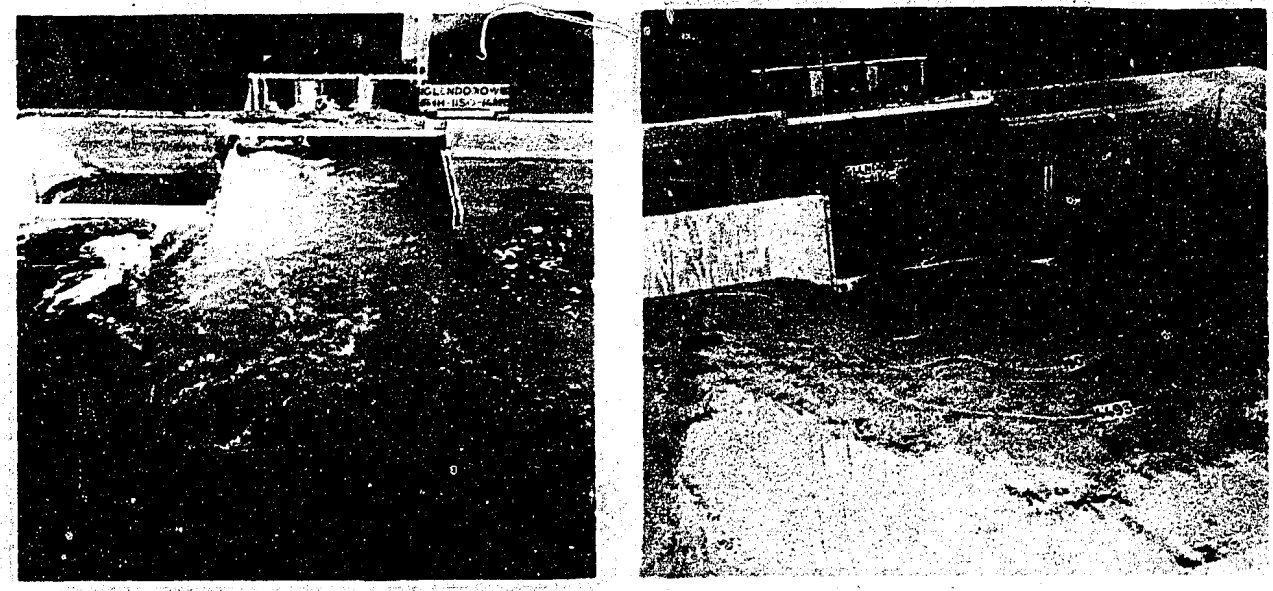
FIGURE 4
REPORT HYD. 413



GLENDO DAM OUTLET WORKS
PRELIMINARY DESIGN
1:24 SCALE MODEL

589

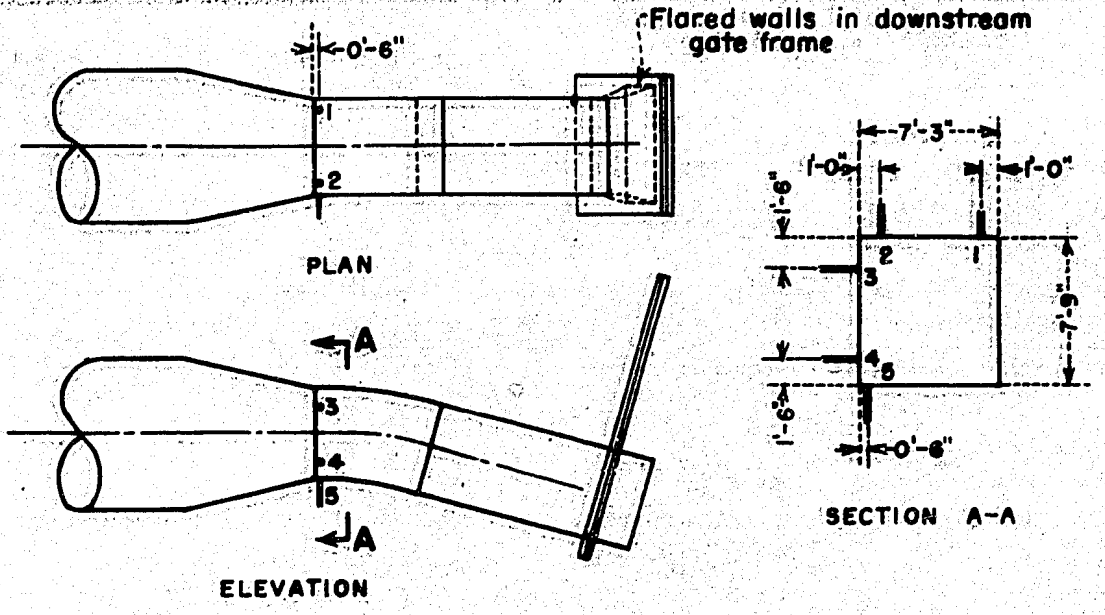
A. The model.



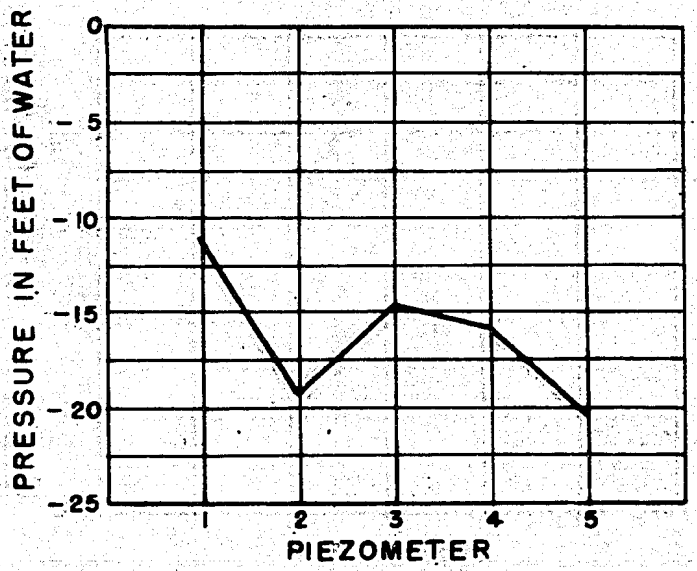
B. Discharge = 11,200 cfs
Gates 100% open.

C. Erosion after discharge
of 11,200 cfs.

GLENDO DAM OUTLET WORKS
Operation of the Preliminary Design
1:24 Scale Model



LOCATION OF PIEZOMETERS IN RIGHT CONDUIT



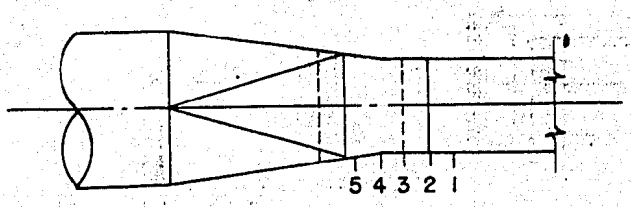
GLENDO DAM OUTLET WORKS

PRESSURES IN PRELIMINARY TRANSITION

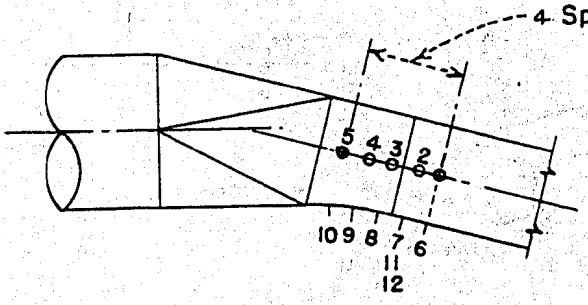
DISCHARGE = 11,200 SECOND FEET

1:24 SCALE MODEL

FIGURE 7
REPORT HYD. 413



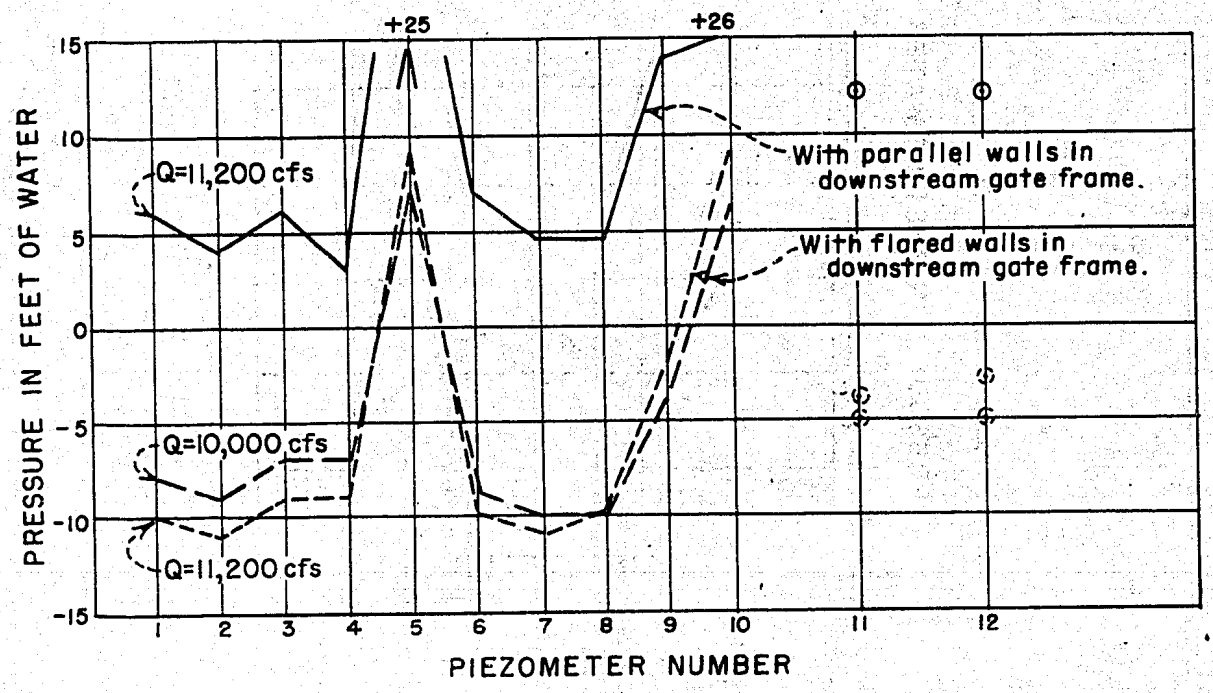
PLAN



ELEVATION

Note: Piezometers 1 thru 10 in right transition. Piezometers 11 thru 12 in center and left transitions respectively.

LOCATION OF PIEZOMETERS IN TRANSITION

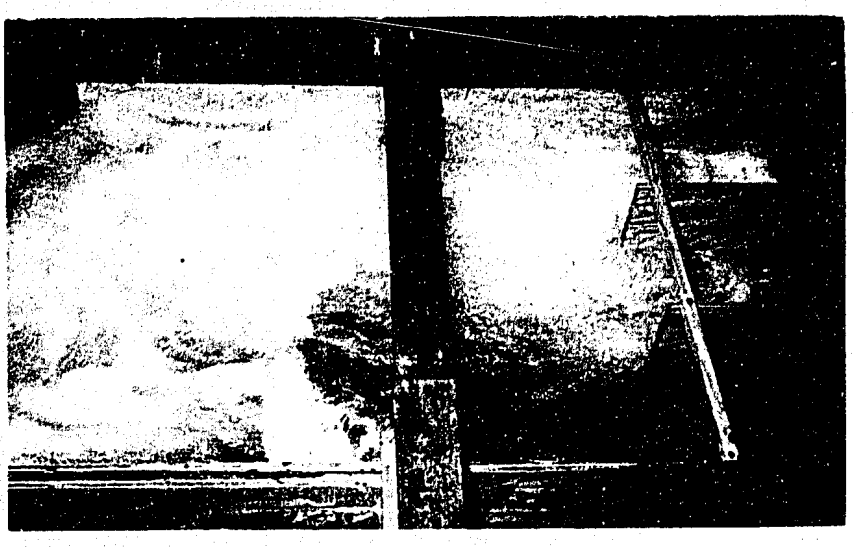


GLENDO DAM OUTLET WORKS

PRESSURES IN RECOMMENDED TRANSITION

GATES 100% OPEN

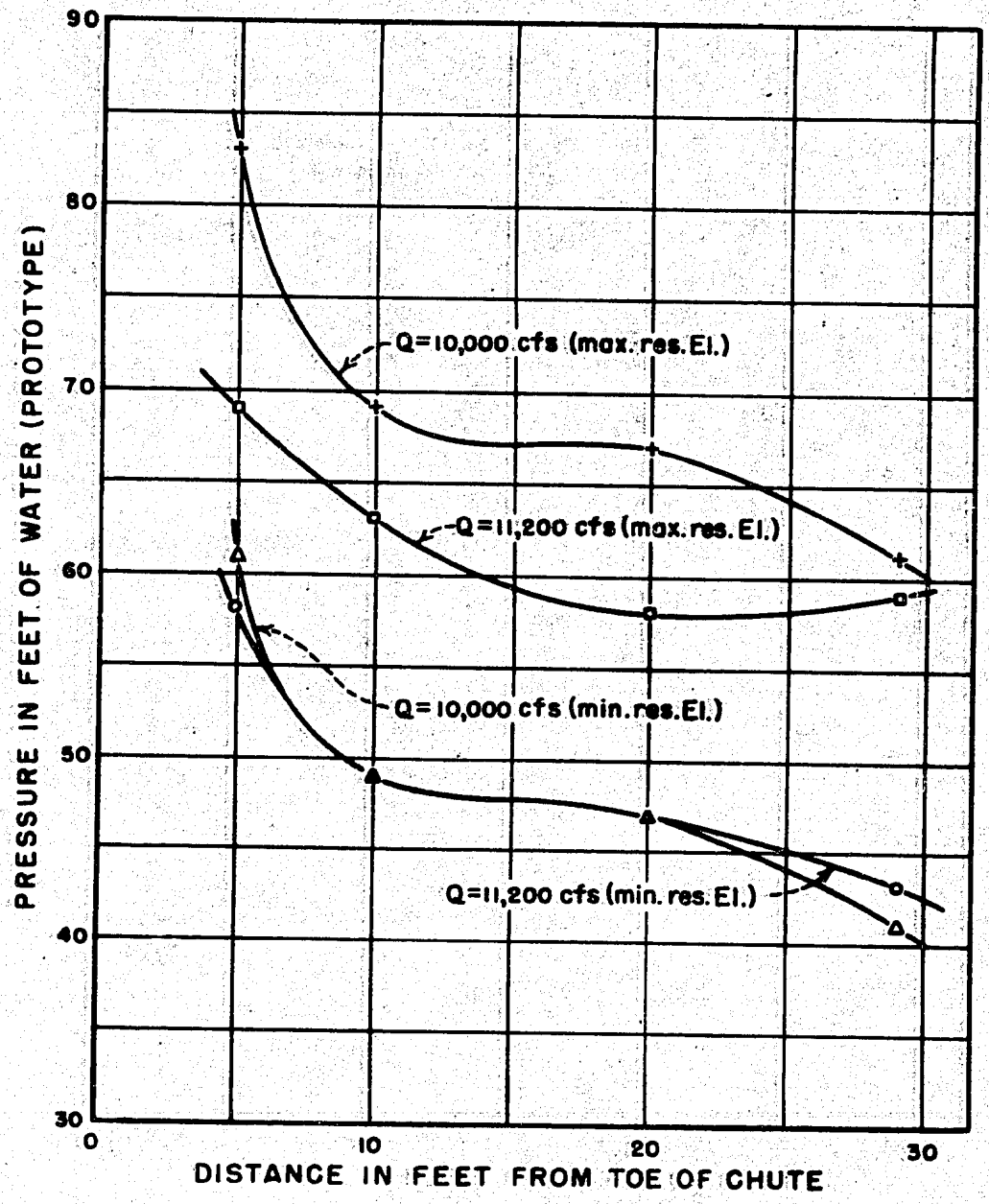
1:24 SCALE MODEL



A. Dividing walls extending to toe of 12° 30' slope.

B. Dividing walls extending 11 feet downstream from toe of slope.

GLENDO DAM OUTLET WORKS
Flow conditions with two lengths of dividing walls
Q = 7470 cfs through right and center gates.
1:24 Scale Model



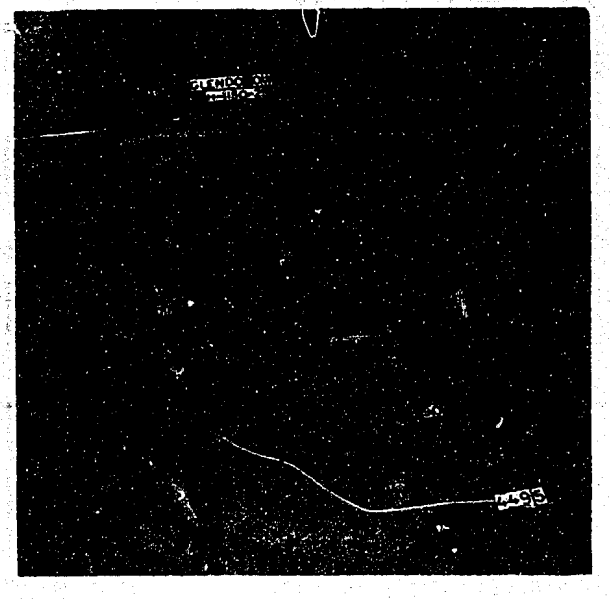
GLENDO DAM OUTLET WORKS

PRESSURES ON FACE OF PIER, 5'-6" SQUARE
LOCATED VARIOUS DISTANCES FROM CHUTE

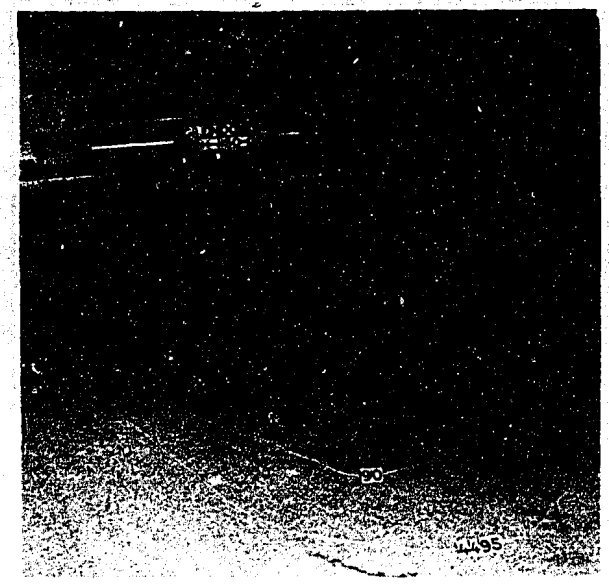
1:24 SCALE MODEL

A. Block and Pier Design 2-C(Table 1).

B. Block and Pier Design 4-C with preliminary transition.

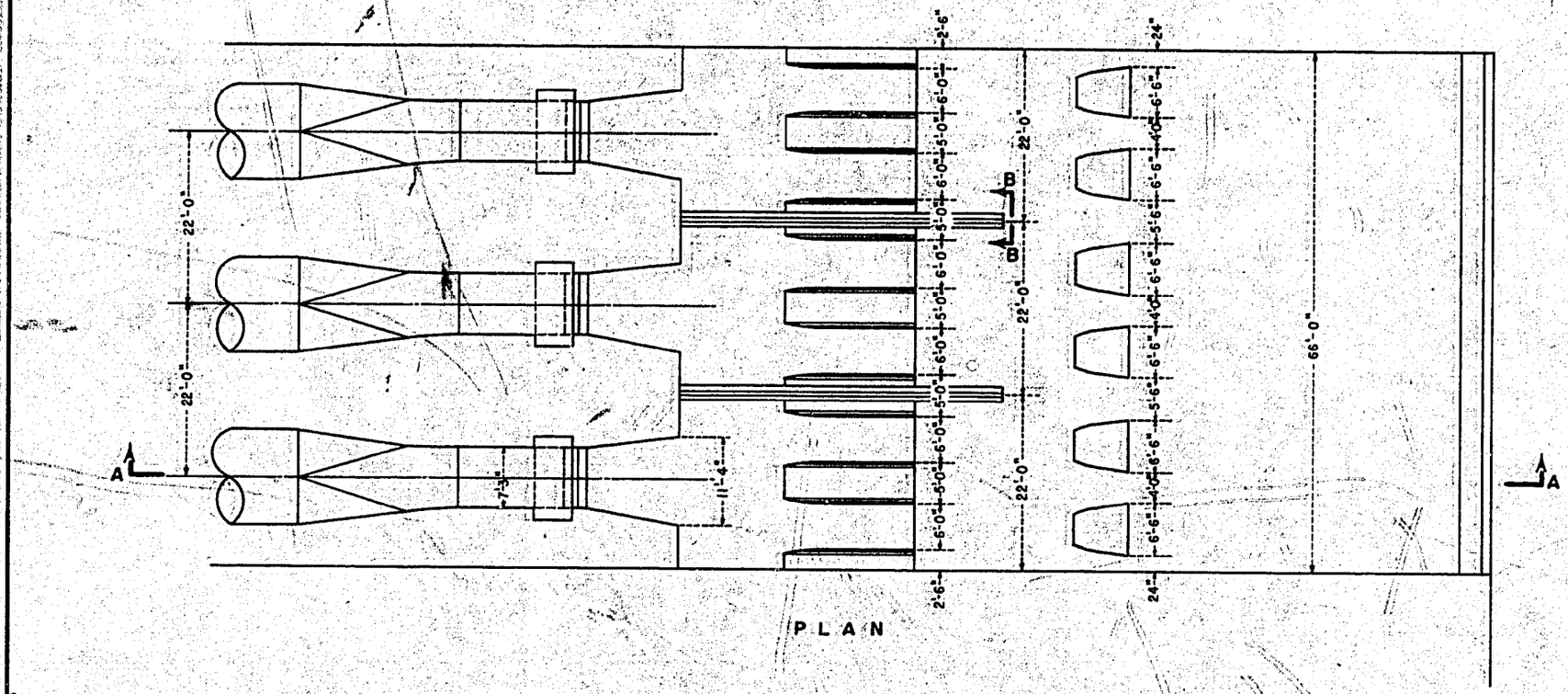


C. Block and Pier Design 4-C with recommended transition.

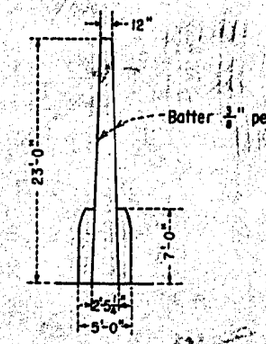


D. Block and Pier Design 5E (Recommended).

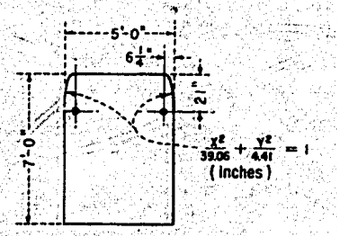
GLENDO DAM OUTLET WORKS
Chute Block and Baffle Pier Studies (see Table 1)
Erosion after Discharge of 11,200 cfs.
1:24 Scale Model



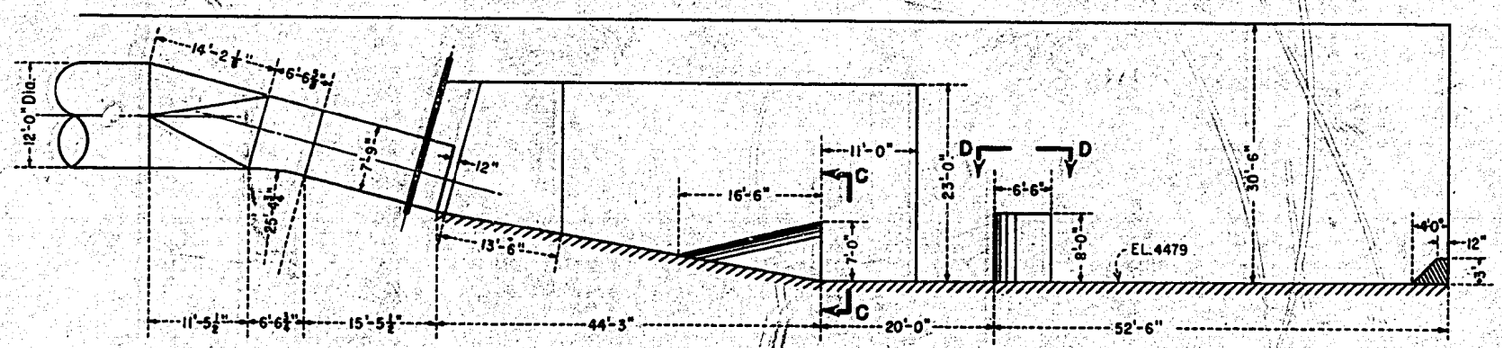
PLAN



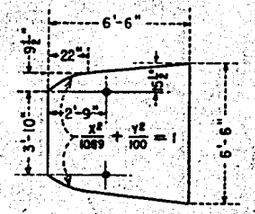
SECTION B–B



SECTION C–C



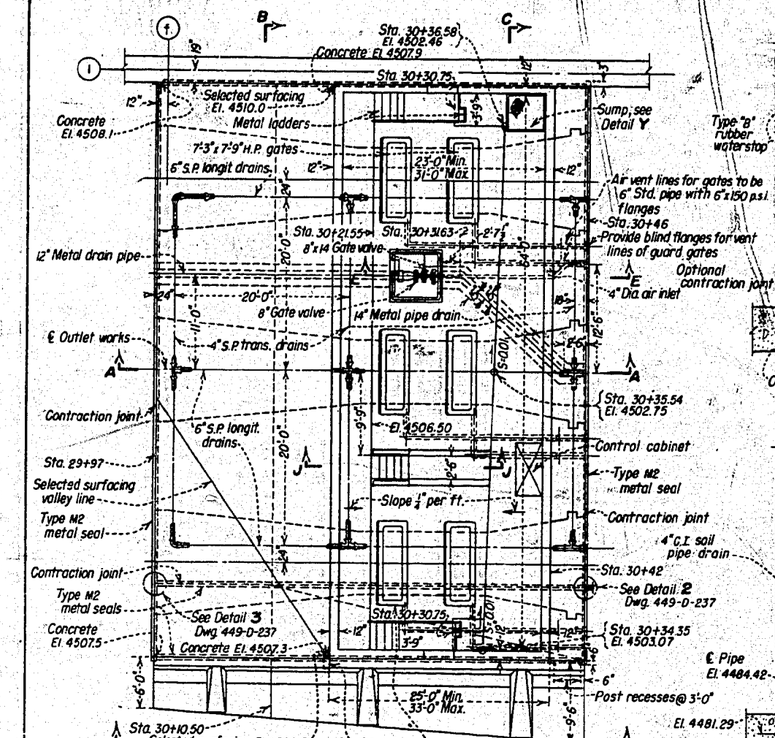
SECTION A–A

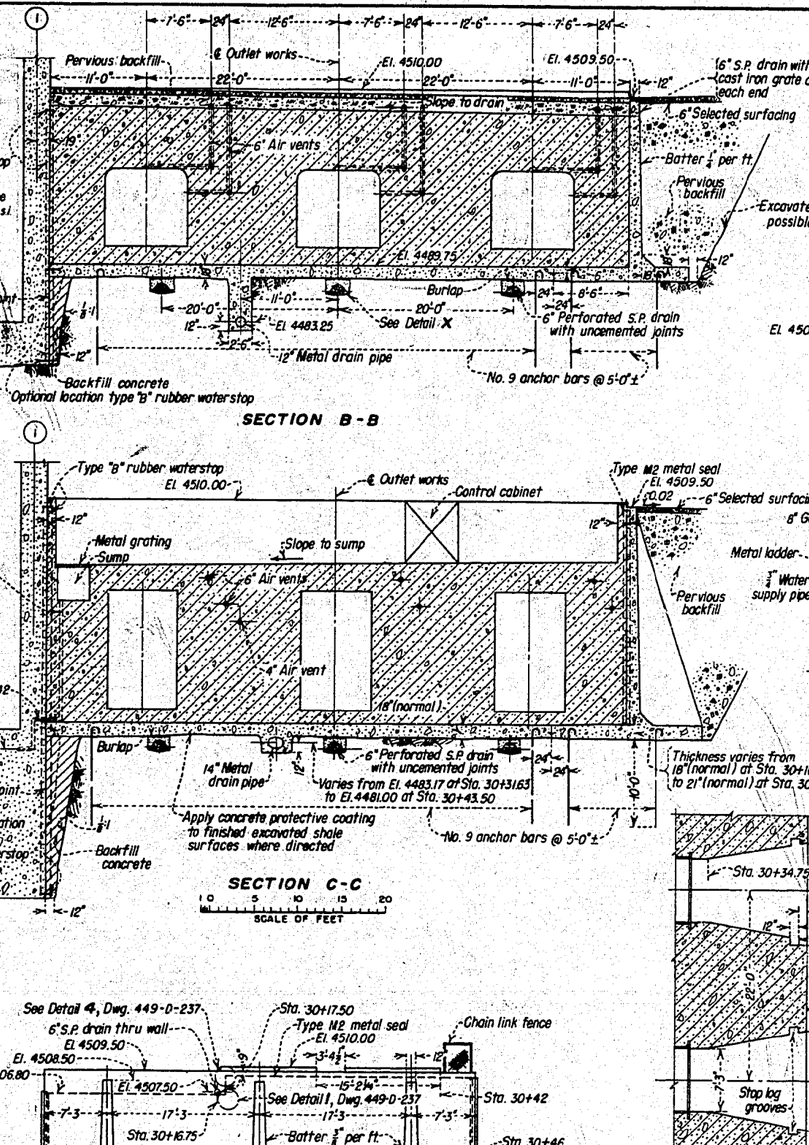


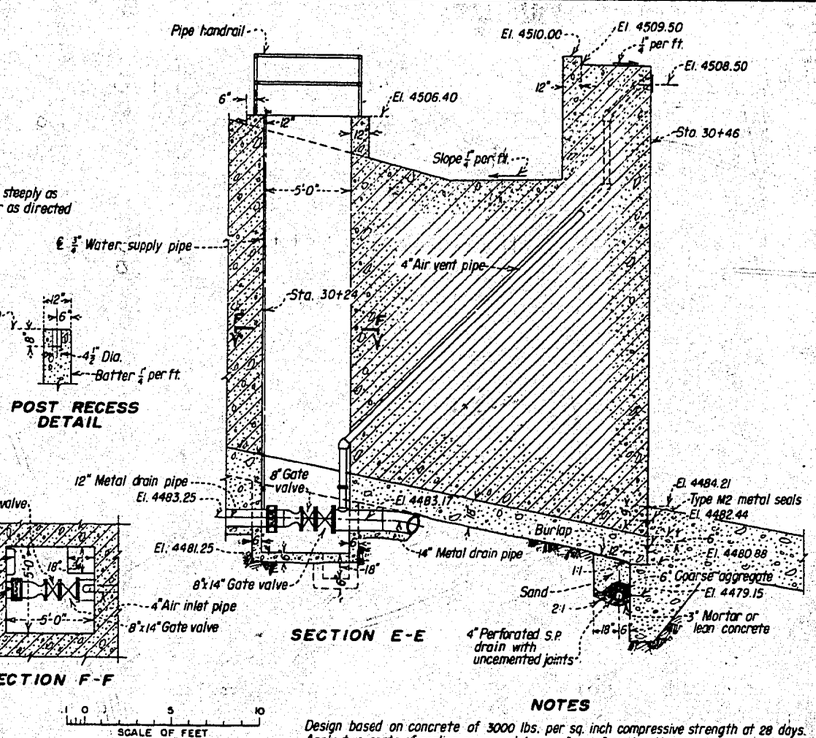
SECTION D–D

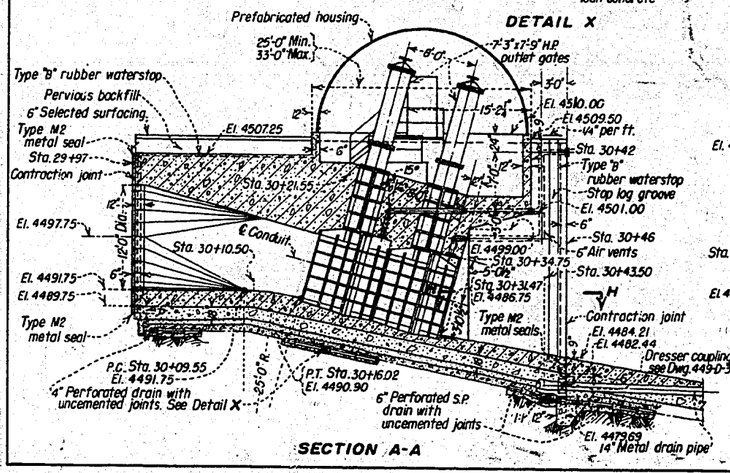
GLENDO DAM OUTLET WORKS
RECOMMENDED DESIGN
1:24 SCALE MODEL

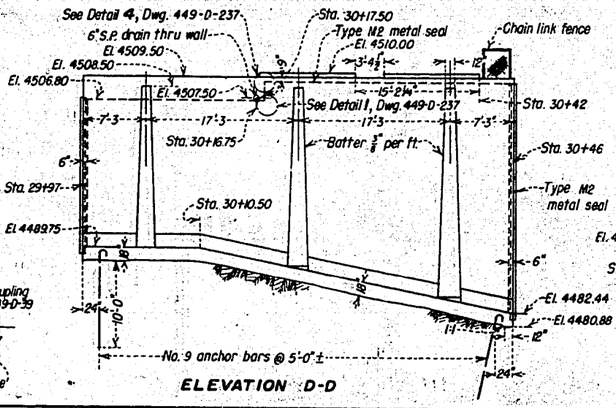
889

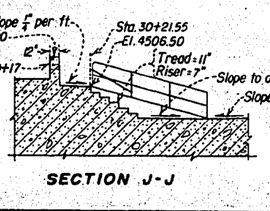












NOTES

Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days.
Apply two coats of sealing compound to one face of contraction joints.
Concrete finishes: surfaces covered by fill, F1 and U1; exposed surfaces, F2 and U2.
(l) and (f) designate Power Plant Wall lines.
S.P. indicates sewer pipe.
Reinforcement not shown.
Chamfer exposed corners ¾".

Designates second stage concrete. (To be placed after diversion.)

Designates backfill concrete.

Anchor bar count: 140 of No. 9 bars.

REFERENCE DRAWINGS

MANIFOLD ANCHOR BLOCK AND SURGE TANK BASE	449-D-52
STILLING BASIN- STA. 30+46 TO STA. 31+48.22	449-D-65
PREFABRICATED METAL HOUSING AND MISCELLANEOUS STRUCTURAL STEEL	449-D-69
PENSTOCK AND OUTLET PIPE	449-D-39
POWER PLANT - SUBSTRUCTURE OUTLINE FLOOR, El. 4470.75 AND SUMP	449-D-146
POWER PLANT - "I" LINE WALL	449-D-151
CONTROL HOUSE FLOOR - STA. 29+97 TO STA. 30+46 REINFORCEMENT	449-D-100
CONTROL HOUSE - RT. WALL - STA. 29+97 TO STA. 30+46 - REINFORCEMENT	449-D-99

6-1-55 D C.A.W.	TRACED; CHANGED DIMENSION TO SEAL. ADDED AIR VENT LINES FOR GATES
5-5-55 D C.A.W.	CHANGED LOCATION "M" METAL DRAIN, ADDED DRAIN AND SEAL DETAILS; MISCELLANEOUS DRAFTING CHANGES; REFERENCE DWGS.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION - GLENDO UNIT - WYOMING

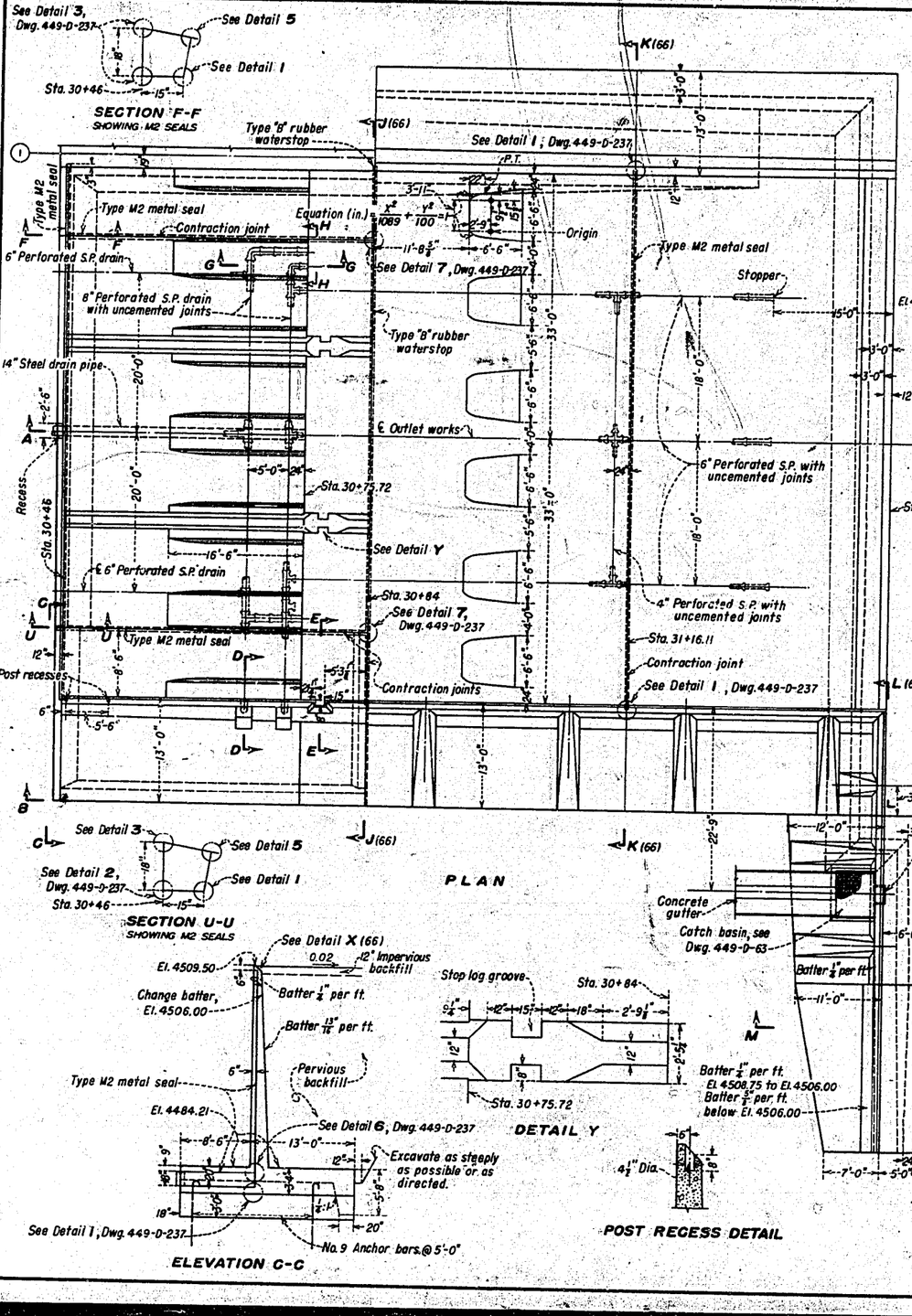
GLENDO DAM
OUTLET WORKS
CONTROL HOUSE

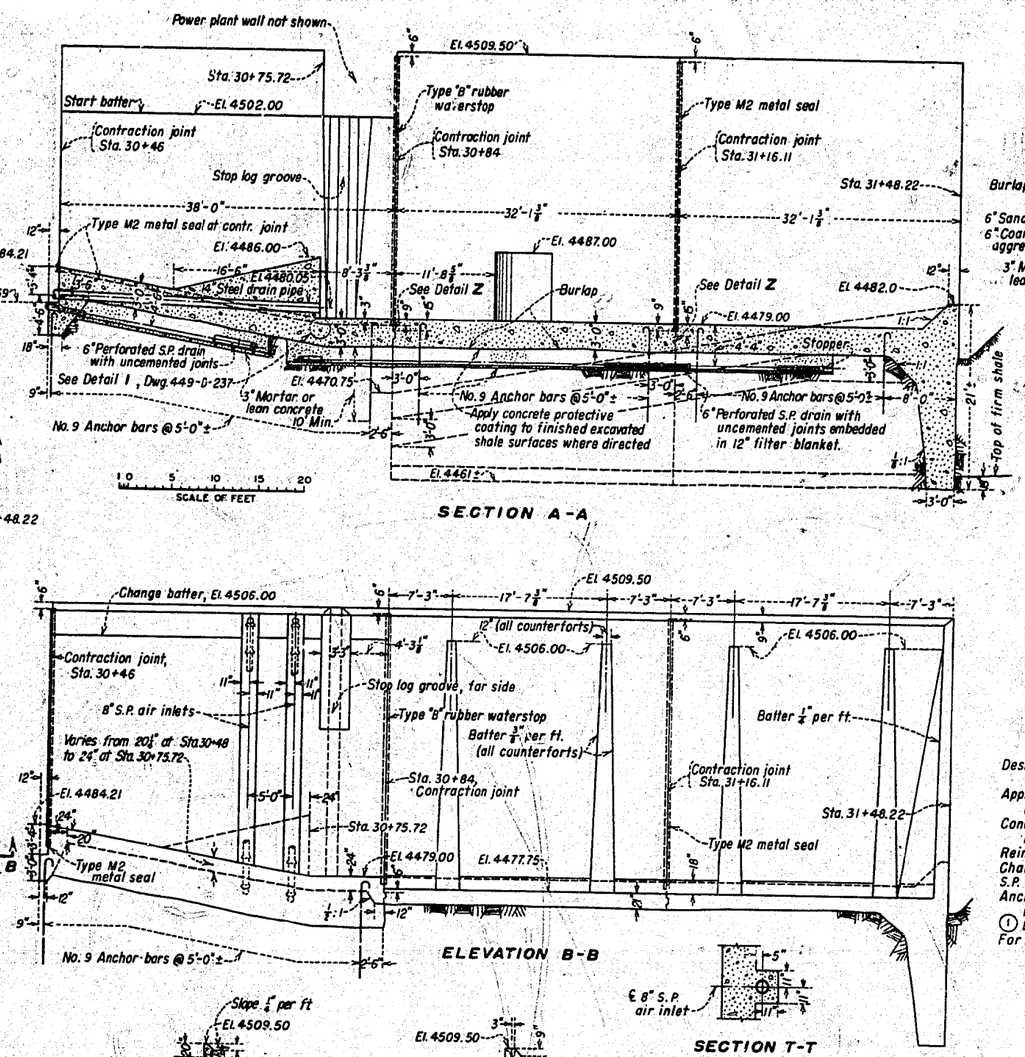
DRAWN	H.G.A.	SUBMITTED	M.A. Jobaro
TRACED	J.F.M.	RECOMMENDED	H.W. Tabor
CHECKED	D.R.E.	APPROVED	J.J. Hammond, CHIEF, DAMS BRANCH

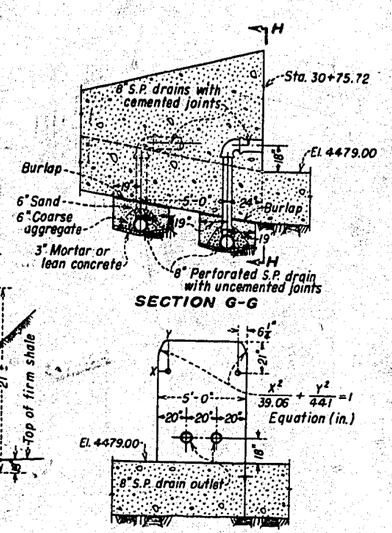
DENVER, COLORADO, MARCH 15, 1954

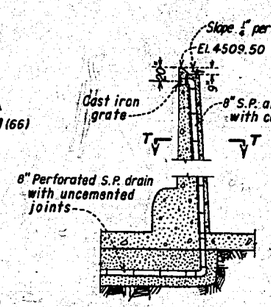
449-D-64

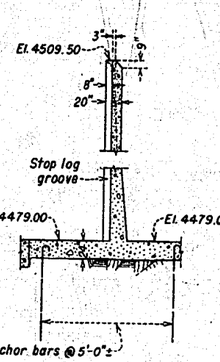
FIGURE 13
REPORT HYD. 413

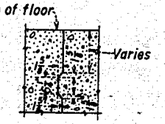












NOTES

Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days.
Apply two coats of sealing compound to one face of contraction joints.
Concrete finishes: Surfaces covered by fill, F1 and U1; exposed surfaces F2 and U2.
Reinforcement not shown.
Chamfer exposed corners 1".
S.P. indicates sewer pipe.
Anchor bar count: 307 of No. 9 bars to extend 10' min. into rock.
(1) Designates power plant wall line.
For reference drawings, see Dwg. 449-D-66.

7-6-56	D Cau	ADDED NOTE ON FLOOR SLAB THICKNESS.
5-12-55	D Cau	TRACED. MOVED STATIONING ARROW.
4-20-55	D C.A.M.	MOVED CONTRACTION JOINT, MOVED 14" STEEL DRAIN, CHANGED WALL BATTER, INCREASED SLAB THICKNESS; ADDED KEY.
10-6-54	D C.E.H.	CHANGED LOCATION OF CATCH BASIN, DRAIN, AND GUTTER.

UNITED STATES
DEPARTMENT OF THE INTERIOR
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MISSOURI RIVER BASIN PROJECT
OREGON TRAIL DIVISION - GLENDO UNIT - WYOMING

GLENDO DAM

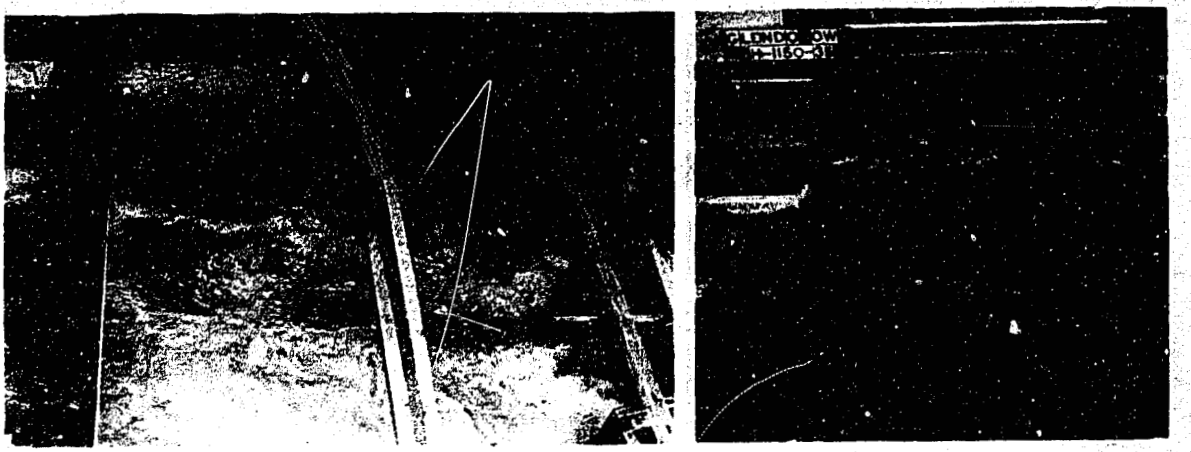
OUTLET WORKS

STILLING BASIN - STA. 30+46 TO STA. 31+48.22

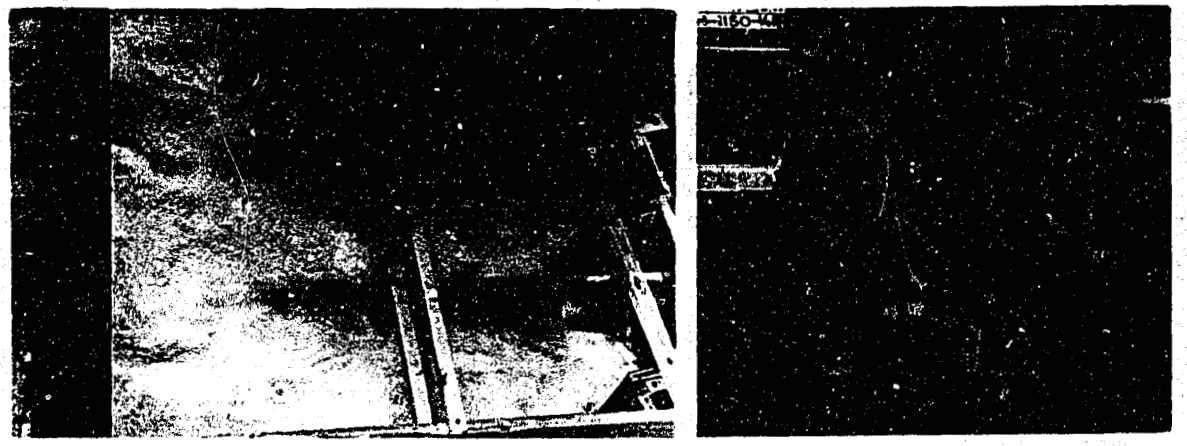
DRAWN M.G.A. SUBMITTED M.A. Jabara
TRACED R.V.S. RECOMMENDED H.W. Tabor
CHECKED C.A.W. APPROVED J.J. Hammond
CHIEF, BASIS BRANCH

DENVER, COLORADO, MAR. 18, 1954
SHEET 1 OF 2

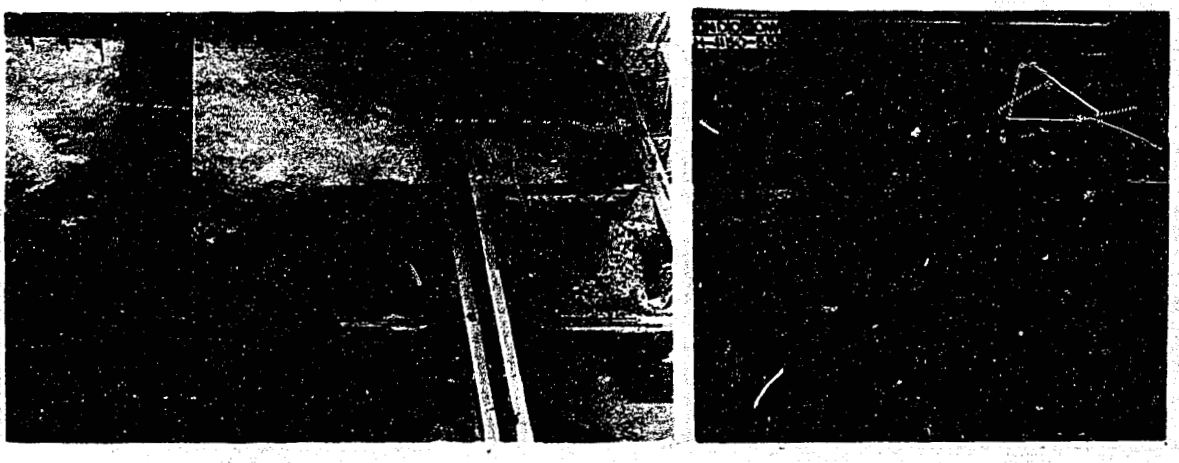
449-D-65



Maximum discharge of 12, 350 cfs through three gates.

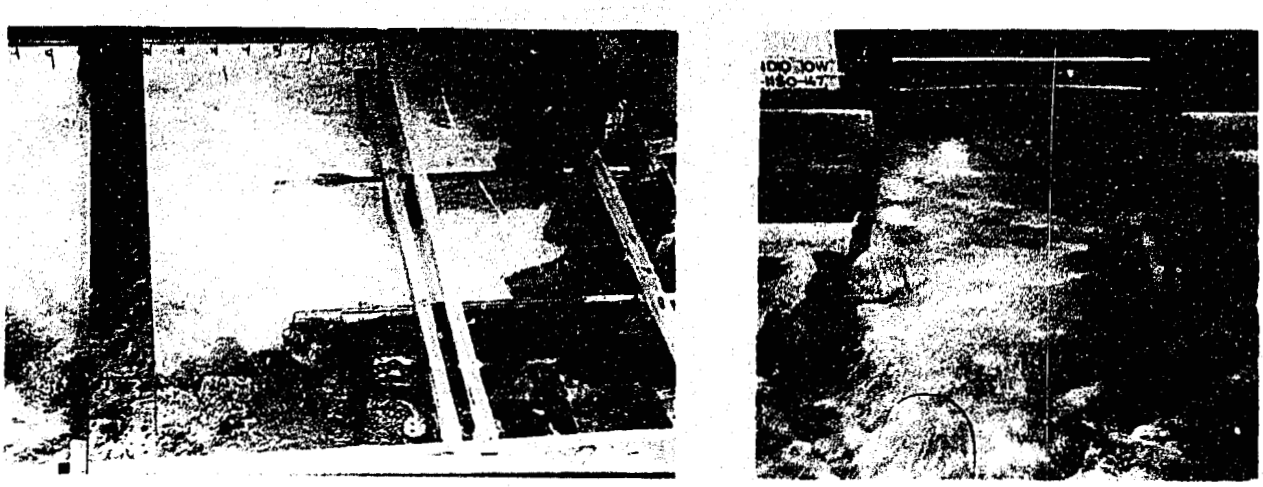


Normal discharge of 10, 000 cfs through 3 gates partly closed.

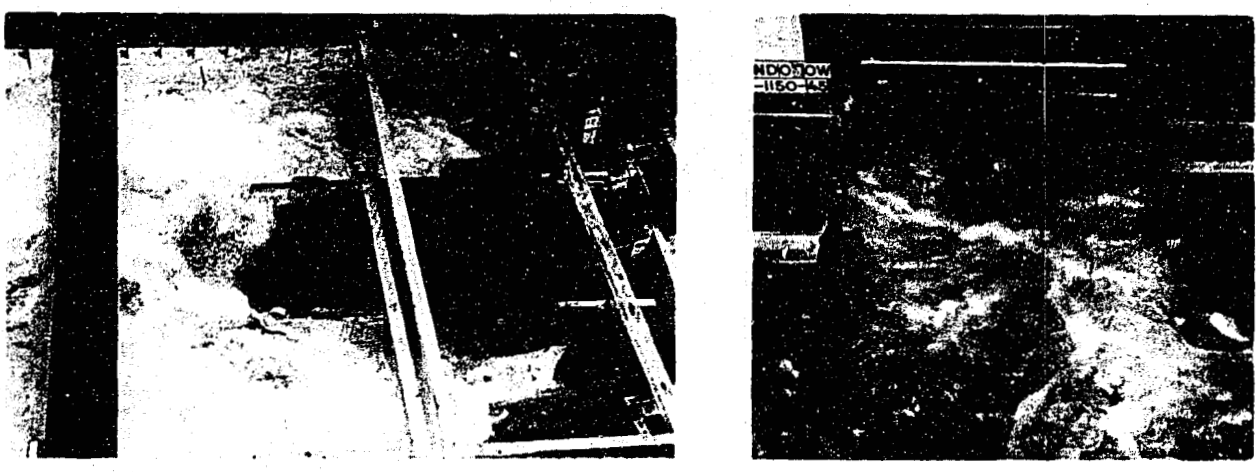


Normal discharge of 3, 800 cfs through right gate fully open.

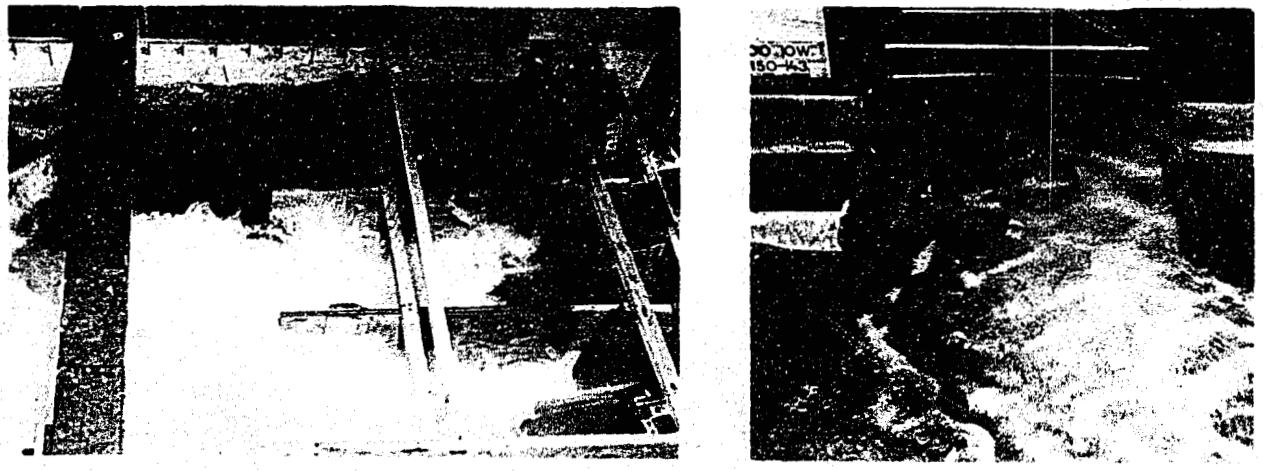
GLENDO DAM OUTLET WORKS
Operation of Recommended Stilling Basin
1:24 Scale Model



Discharge of 8,300 cfs through right and center gates.



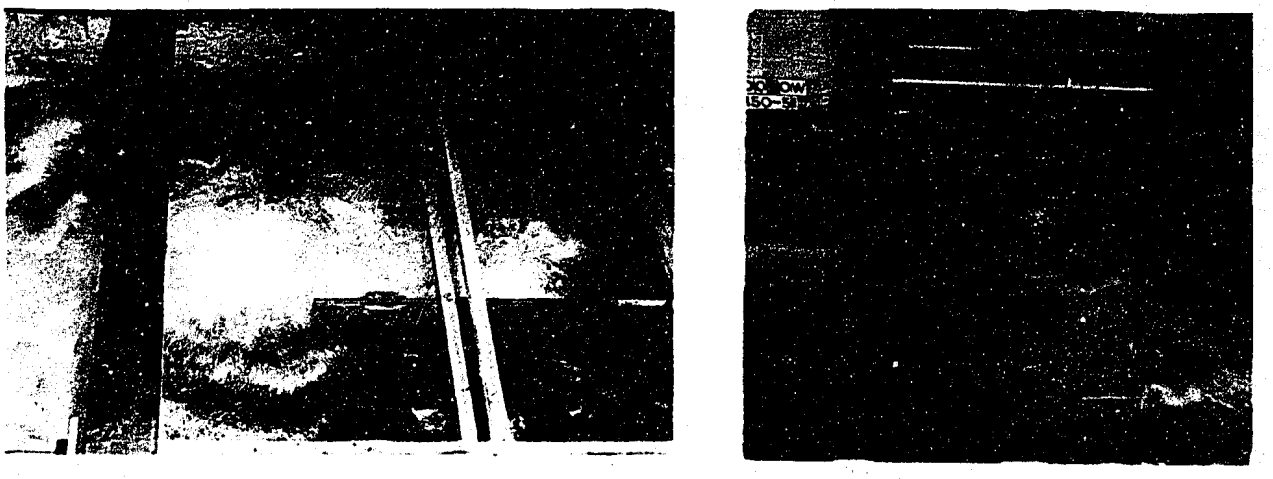
Discharge of 8,600 cfs through right and left gates.



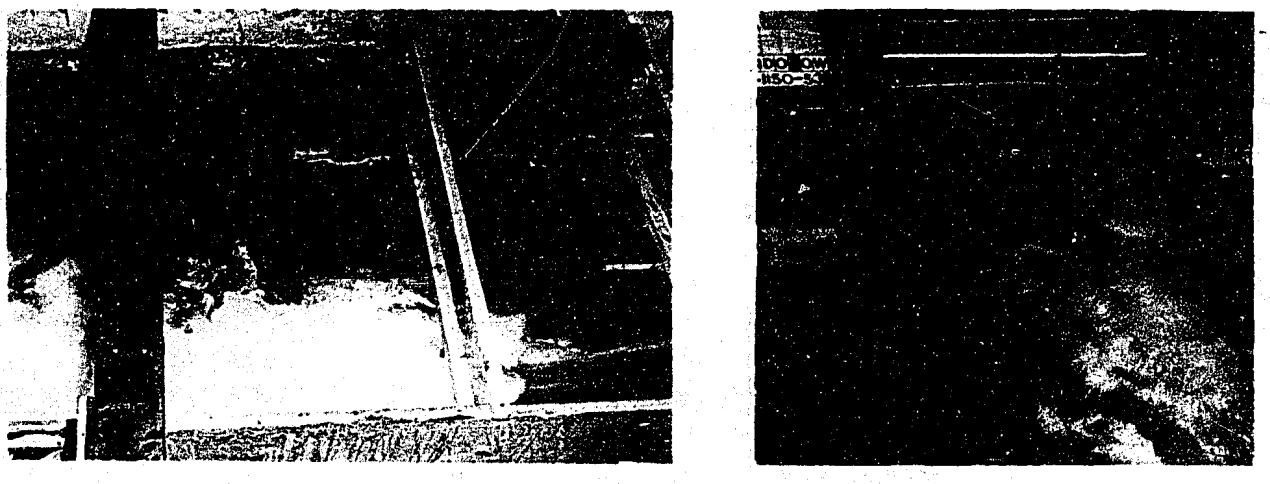
Discharge of 8,700 cfs through center and left gates.

GLENDO DAM OUTLET WORKS
Operation of Recommended Stilling Basin
1:24 Scale Model

A. Discharge of 4,600 cfs through right gate.



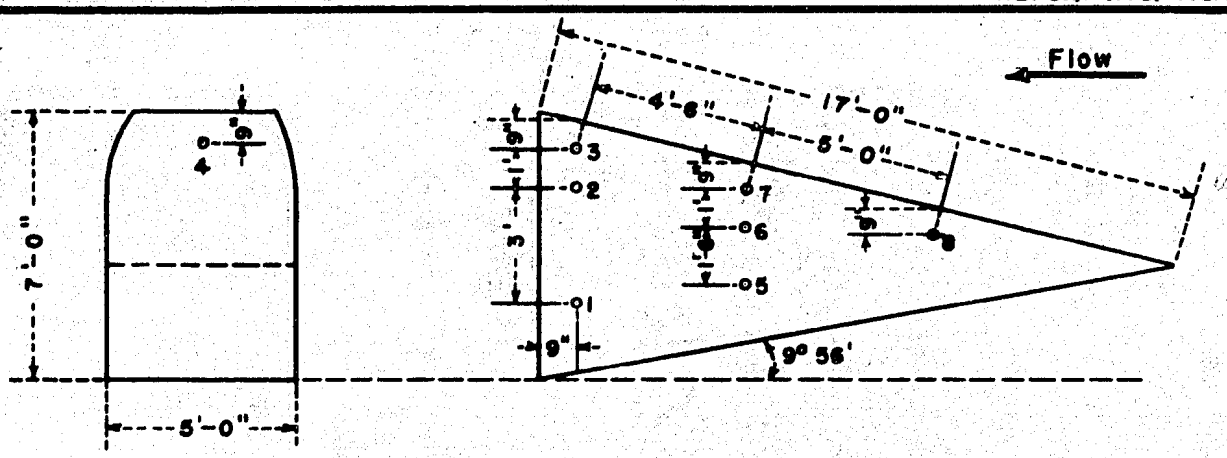
B. Discharge of 4,700 cfs through center gate.



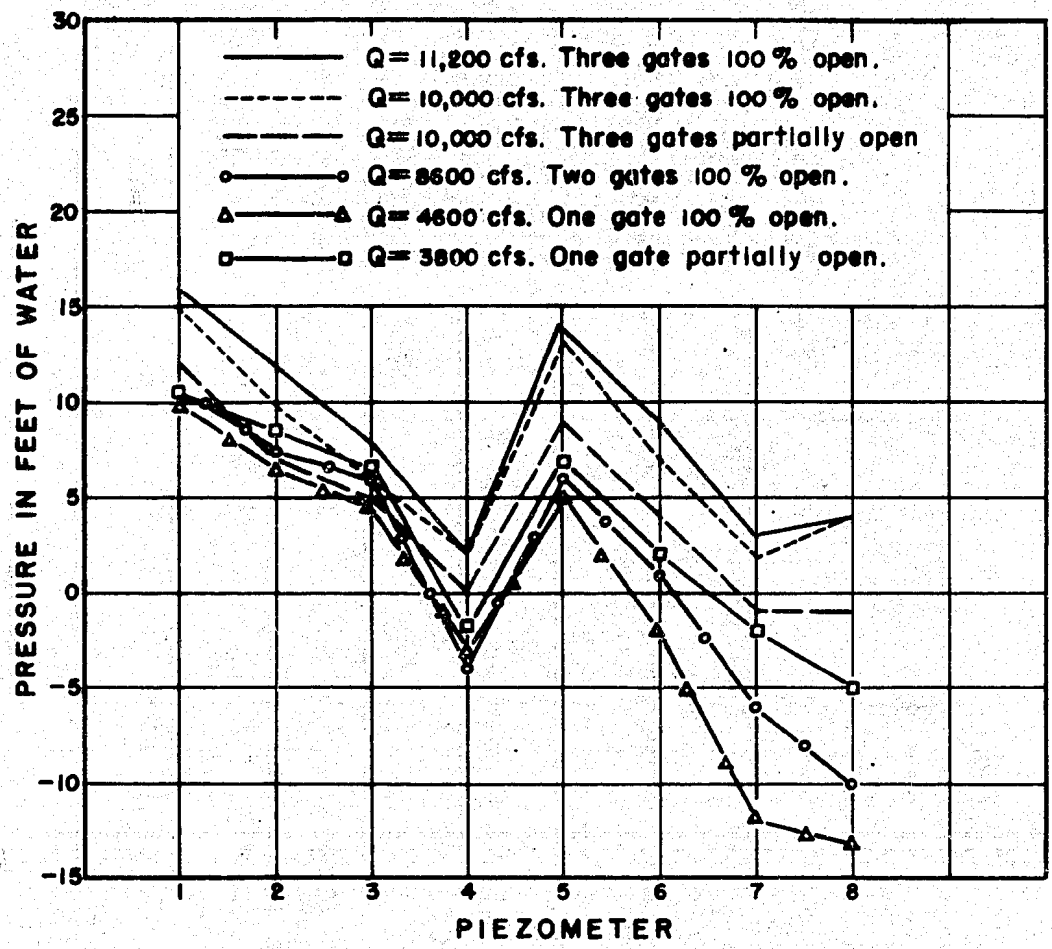
C. Discharge of 4,750 cfs through left gate.

GLENDO DAM OUTLET WORKS
Operation of Recommended Stilling Basin
1:24 Scale Model

FIGURE 17
REPORT HYD. 413



LOCATION OF PIEZOMETERS ON TEST BLOCK

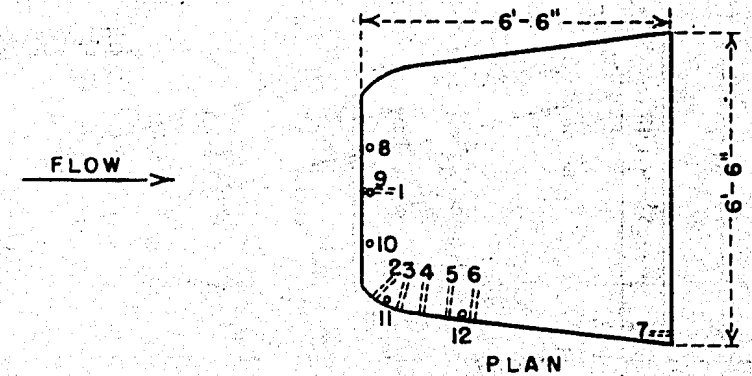


GLENDO DAM OUTLET WORKS

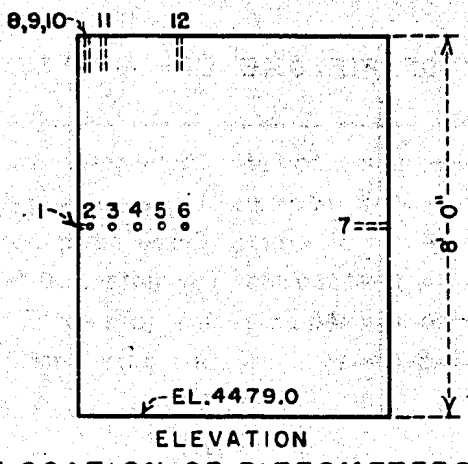
PIEZOMETRIC PRESSURE ON RECOMMENDED CHUTE BLOCK LOCATED IN CENTER OF RIGHT BAY

1:24 SCALE MODEL

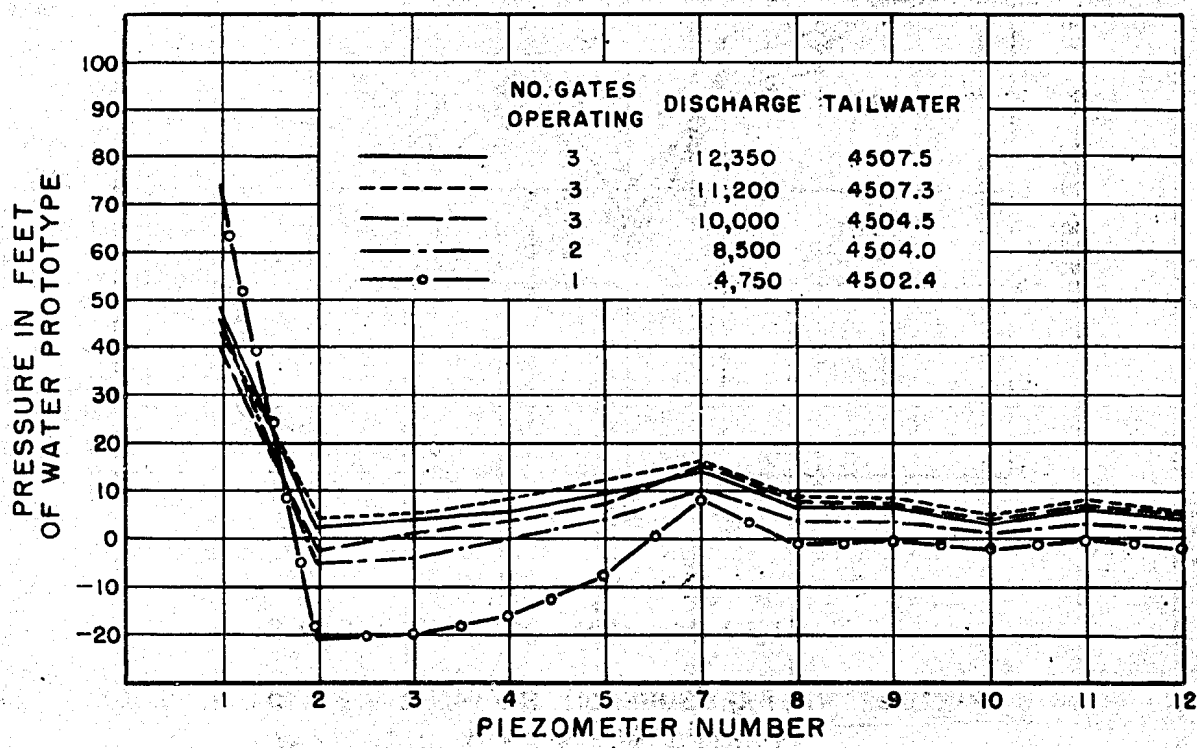
FIGURE 18
REPORT HYD. 413



Note: Piezometer 6 plugged.
No data obtained.



LOCATION OF PIEZOMETERS

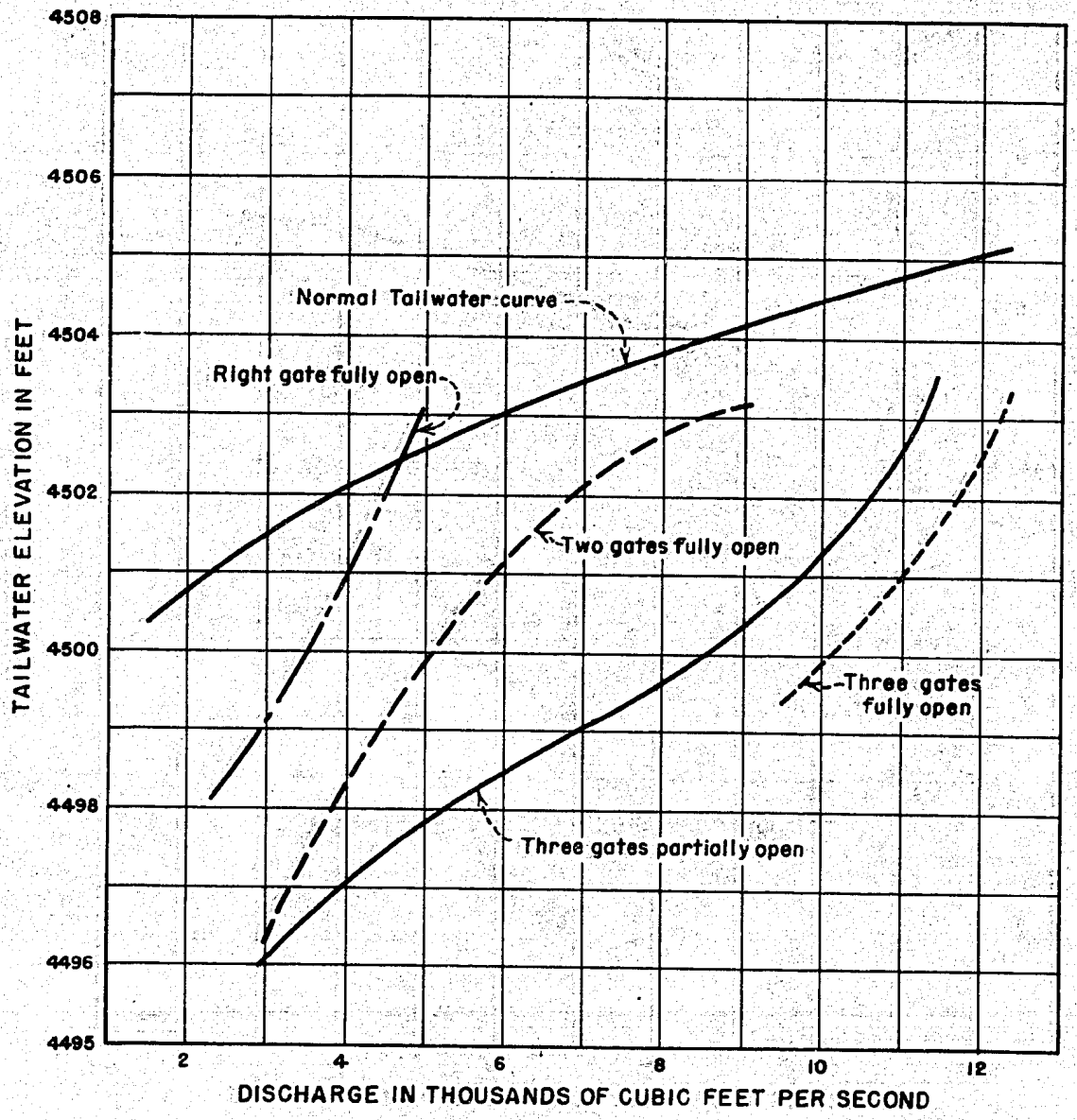


GLENDO DAM OUTLET WORKS

PIEZOMETRIC PRESSURES ON RECOMMENDED BAFFLE PIERS

1:24 SCALE MODEL

559

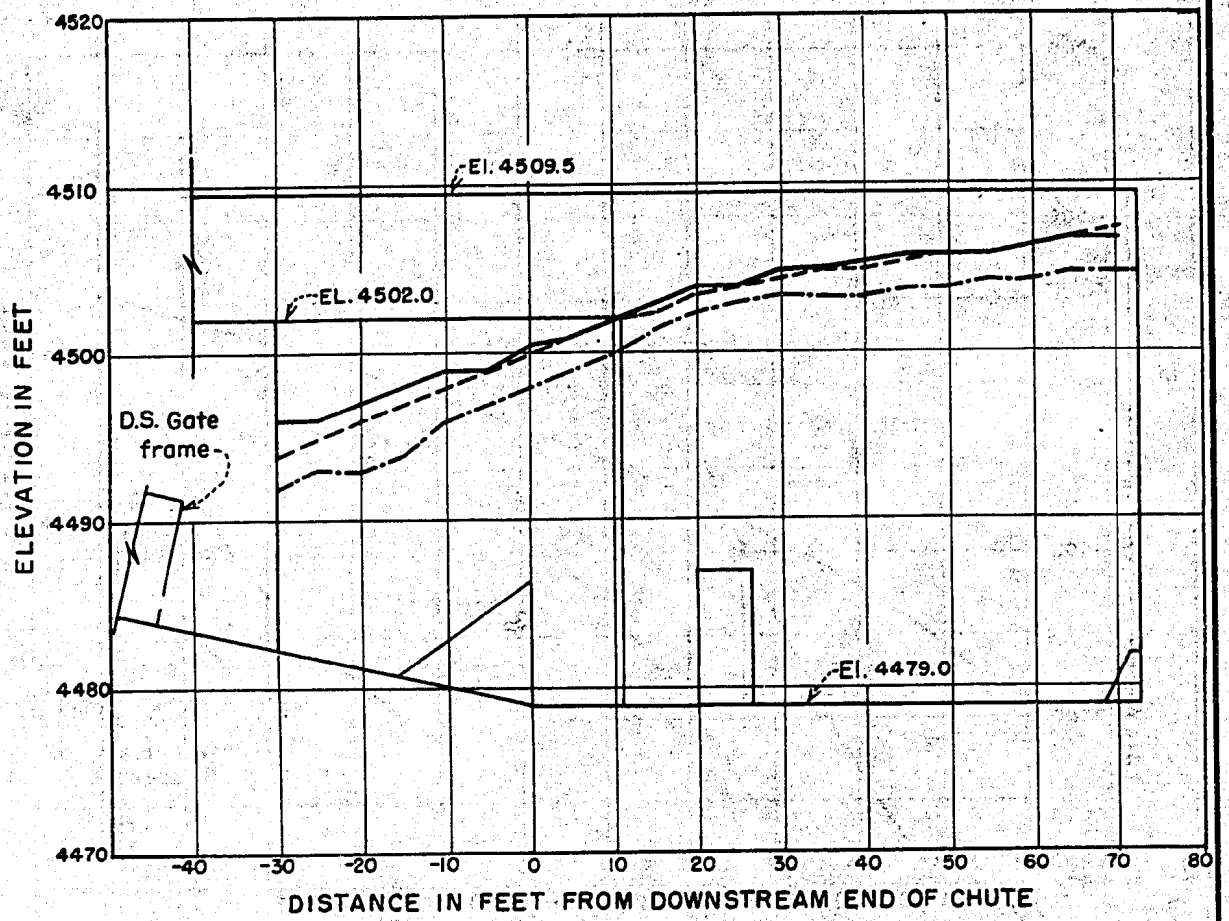


GLENDO DAM OUTLET WORKS

JUMP SWEEP-OUT CURVES
RECOMMENDED DESIGN

1:24 SCALE MODEL

FIGURE 20
REPORT HYD. 413

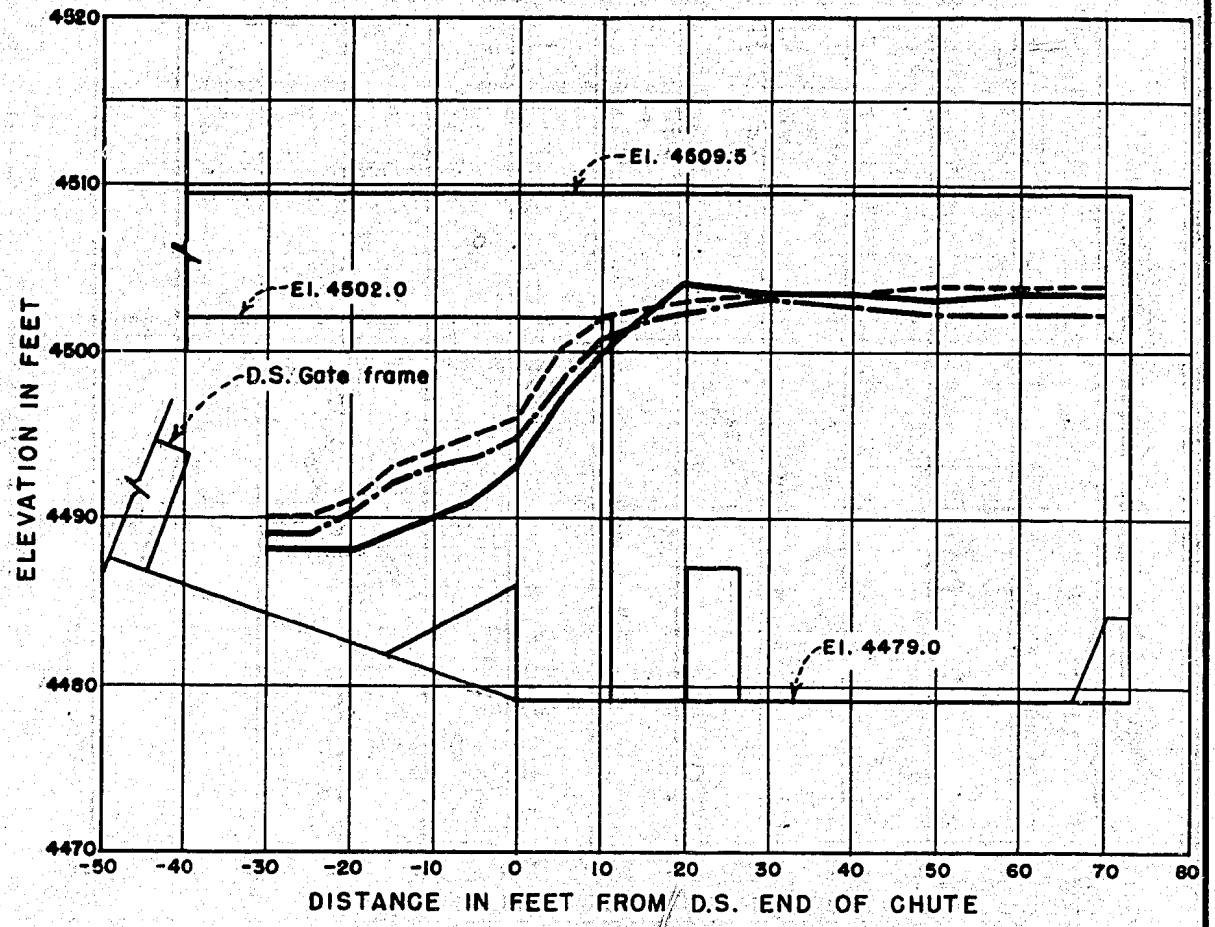


For discharge of 11,200 c.f.s through three gates (Fully open)
For discharge of 12,350 c.f.s through three gates (Fully open)
For discharge of 10,000 c.f.s through three gates (Partially closed)

GLENDO DAM OUTLET WORKS

WATER SURFACE PROFILES ALONG RIGHT TRAINING WALL
RECOMMENDED DESIGN

1:24 SCALE MODEL



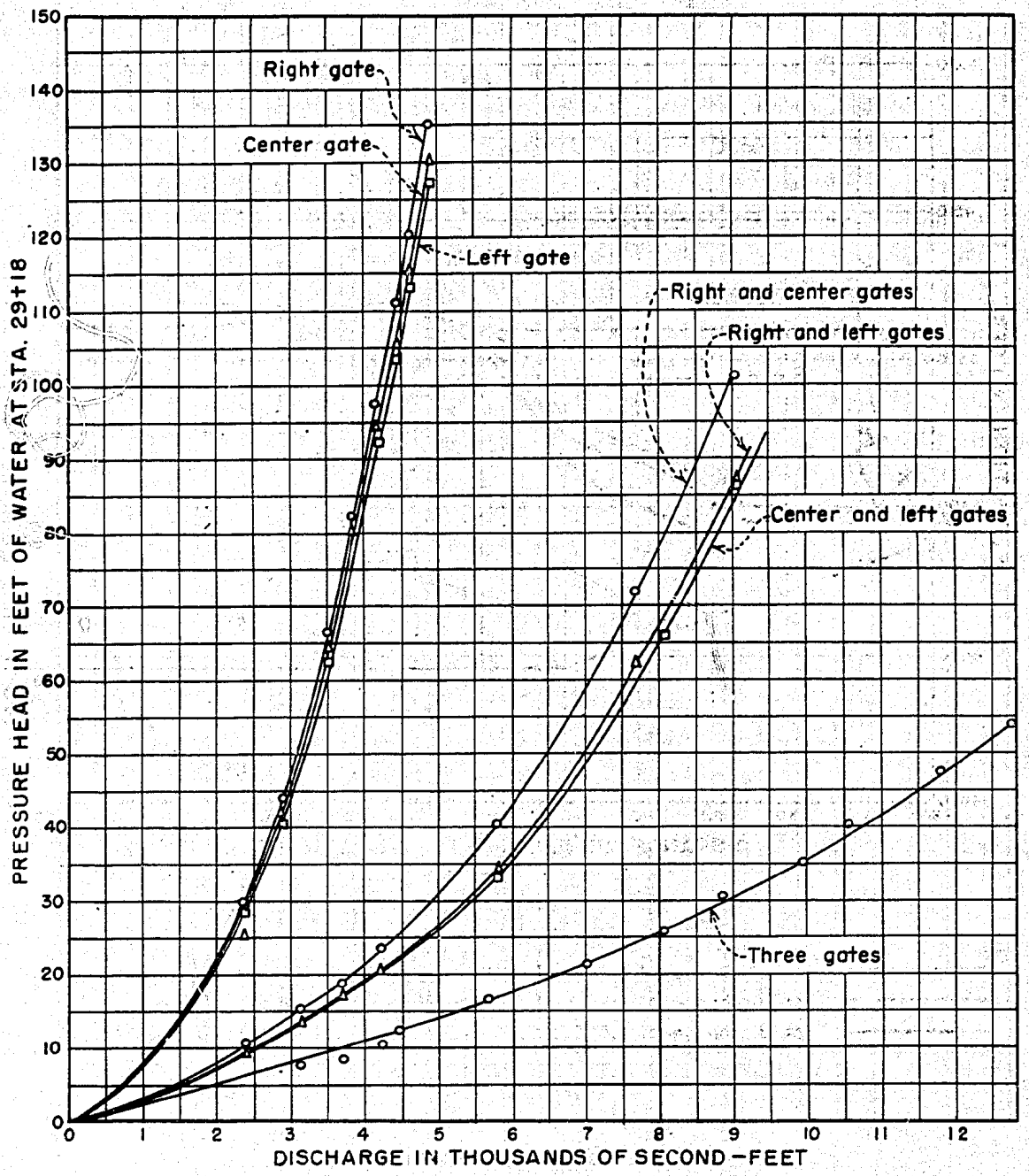
For discharge of 8,700 c.f.s. through two gates (Center closed)
For discharge of 8,400 c.f.s. through two gates (Left closed)
For discharge of 3,800 c.f.s through right gate (Center and left closed)

GLENDO DAM OUTLET WORKS

WATER SURFACE PROFILES ALONG RIGHT TRAINING WALL
RECOMMENDED DESIGN

1:24 SCALE MODEL

FIGURE 22
REPORT HYD. 413



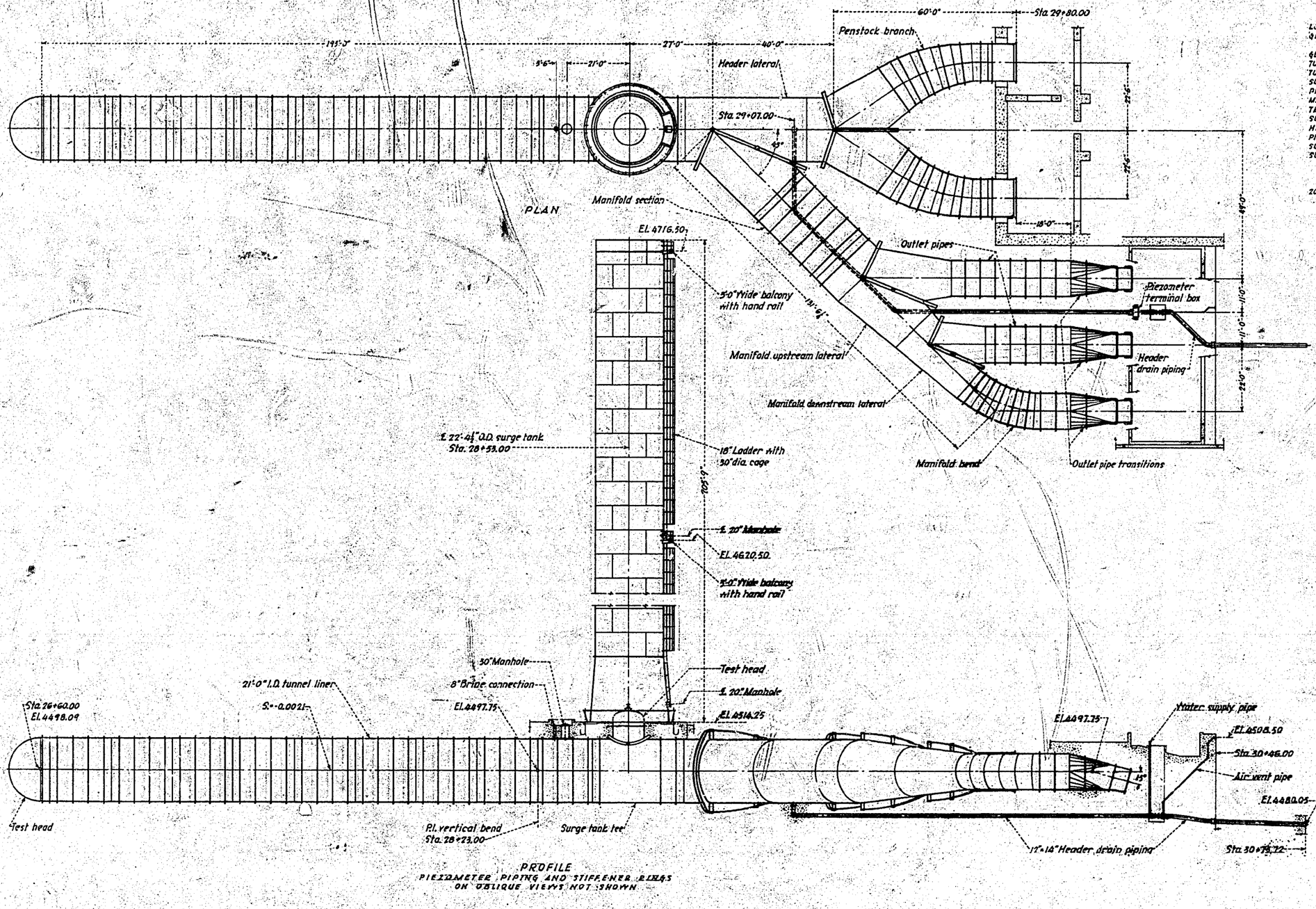
GLENDO DAM OUTLET WORKS

HEAD-DISCHARGE CURVES WITH GATE(S) FULLY OPEN

RECOMMENDED DESIGN WITH REINFORCING POSTS INSTALLED IN Y-BRANCHES

1:24 SCALE MODEL

559



LIST OF DRAWINGS

LOCATION MAP	449-D-110
GENERAL PLAN	449-D-121
PENSTOCK, SURGE TANK AND OUTLET PIPES	
GENERAL ARRANGEMENT - LIST OF DRAWINGS	449-D-175
TUNNEL LINER - SHEET 1 OF 2	449-D-176
TUNNEL LINER - SHEET 2 OF 2	449-D-177
SURGE TANK TEE-HEADER LATERAL-MANIFOLD SECTION	449-D-178
PENSTOCK BRANCH	449-D-179
MANIFOLD LATERAL AND BEND	449-D-180
TRANSITIONS-OUTLET PIPES-TEST HEADS	449-D-181
SURGE TANK ANCHOR BOLTS	449-D-182
HEADER DRAIN PIPING	449-D-183
PIEZOMETER PIPING	449-D-184
SURGE TANK - SHEET 1 OF 2	449-D-185
SURGE TANK - SHEET 2 OF 2	449-D-186
20" MANHOLE (STANDARD DRAWING)	80-D-4556

REV.	DATE	BY	CHK'D	APP'D	DESCRIPTION
10	10-14	WH			Relocated 14" drain piping
9	7-57	LB			Balconies removed and ladders relocated

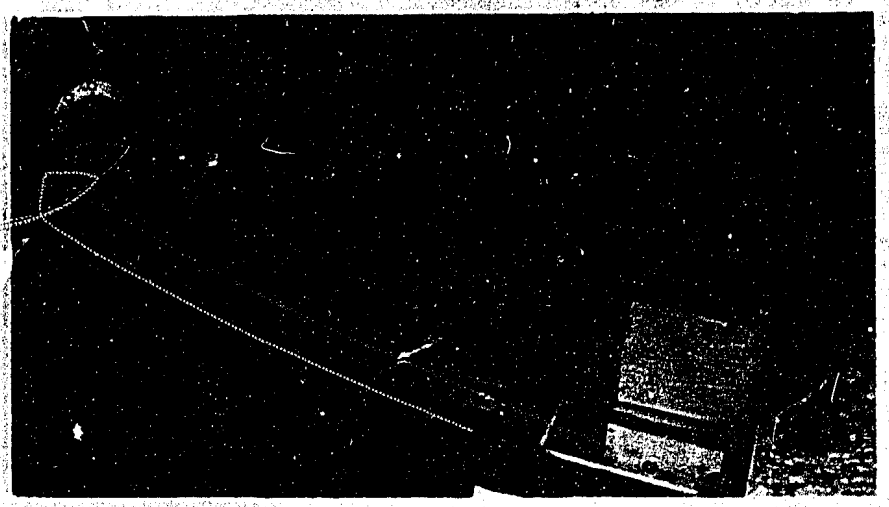
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
GLENDO UNIT - WYOMING

GLENDO DAM

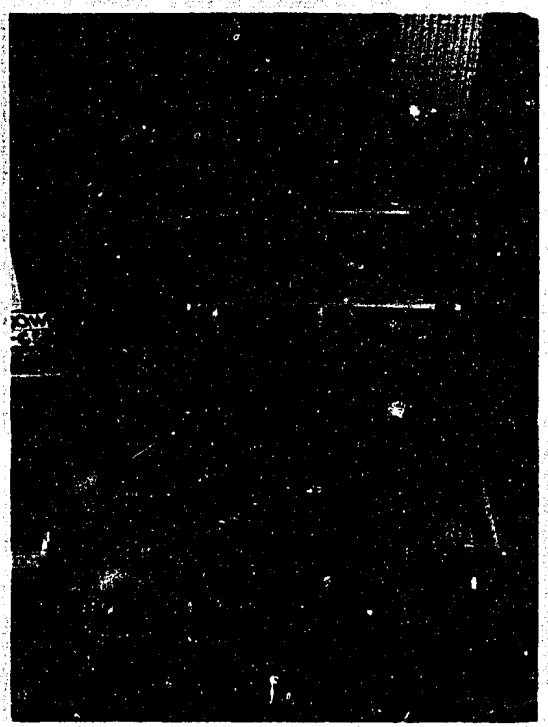
PENSTOCK, SURGE TANK AND OUTLET PIPES
GENERAL ARRANGEMENT - LIST OF DRAWINGS

DRAWN: VM — SUBMITTED: F. Heidin
TRACED: — RECOMMENDED: J. Moore
CHECKED: WH — APPROVED: [illegible]
DENVER, COLORADO — DATE: [illegible]

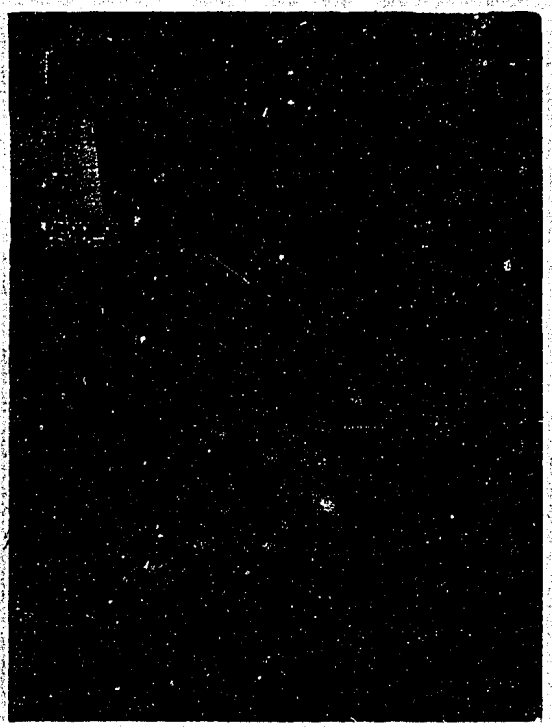
449-D-175



A. Model for diversion studies.



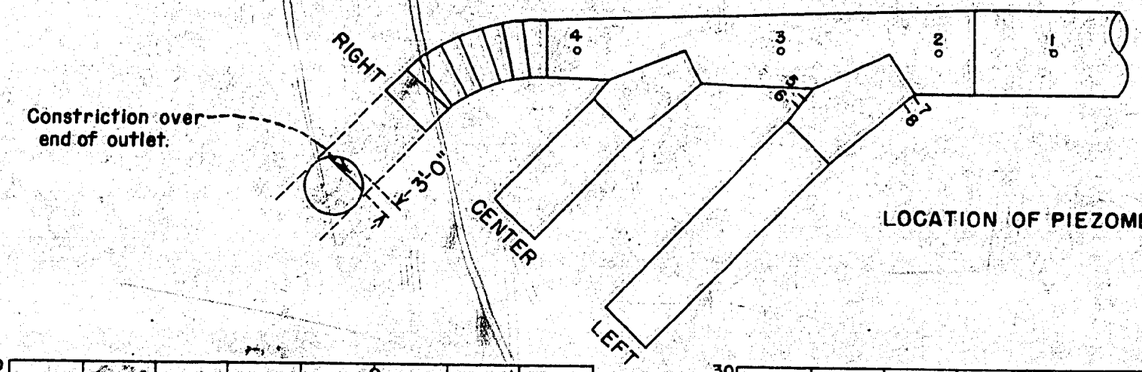
Right and left outlets flowing full. Center outlet partially full.



Right outlet flowing full. - Center and left outlets partially full.

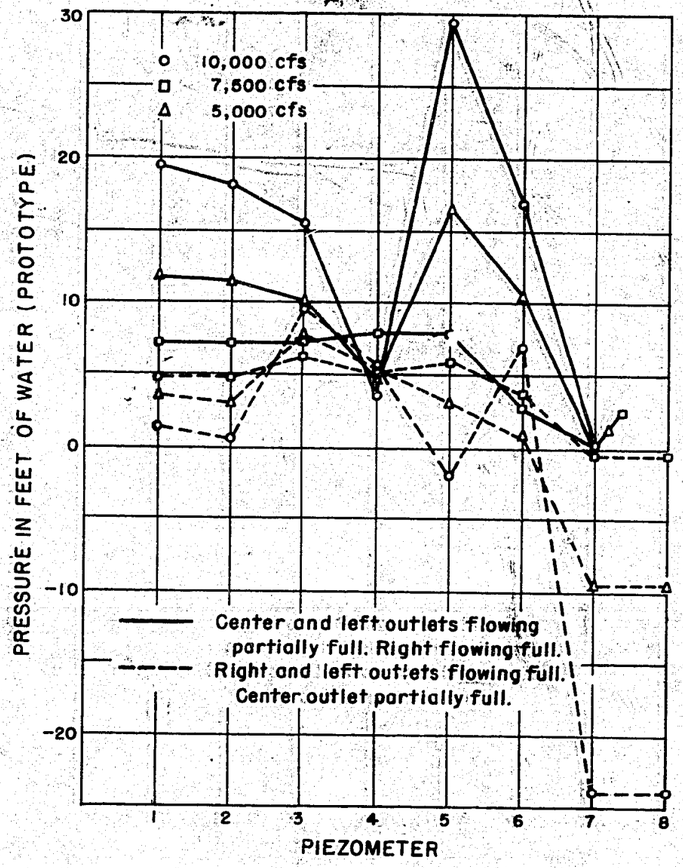
B. Maximum diversion discharge of 10,000 cfs.

GLENDO DAM OUTLET WORKS
Preliminary Diversion Studies
1:24 Scale Model

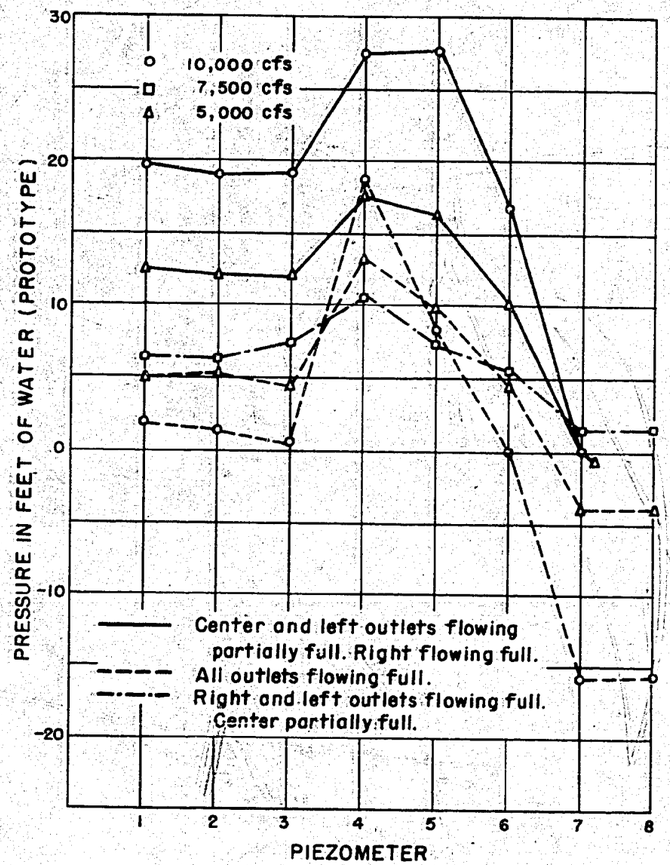


LOCATION OF PIEZOMETERS

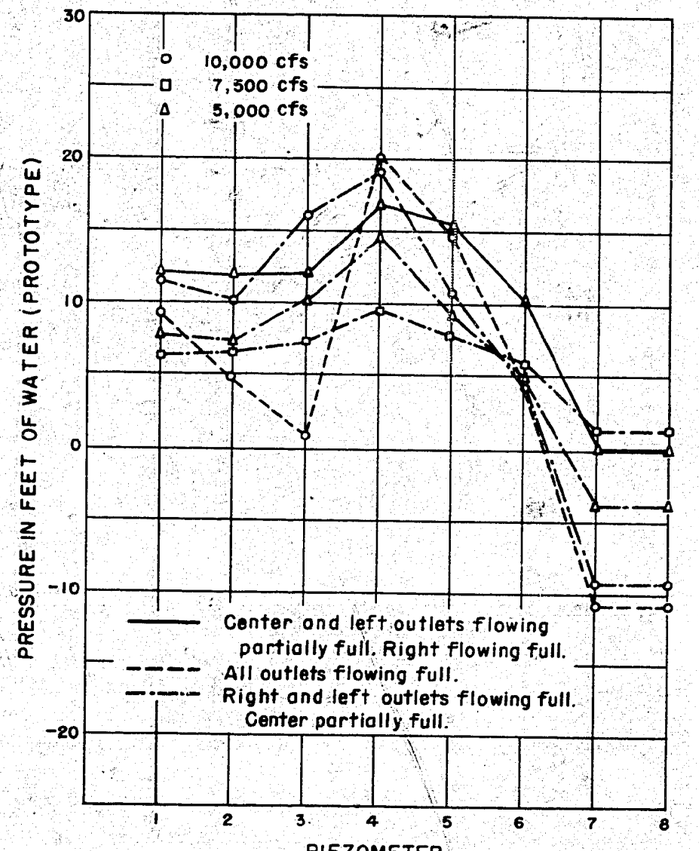
Note: Where no pressure for Piezometer 8 is shown, flow was open channel in left outlet and pressure was atmospheric.



A. NO CONSTRICTIONS ON OUTLETS (PRELIMINARY)



B. CONSTRICTION ON RIGHT OUTLET

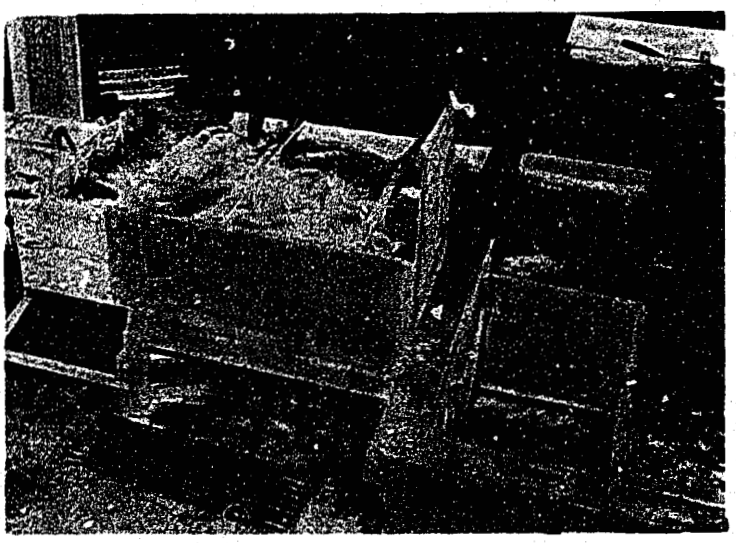


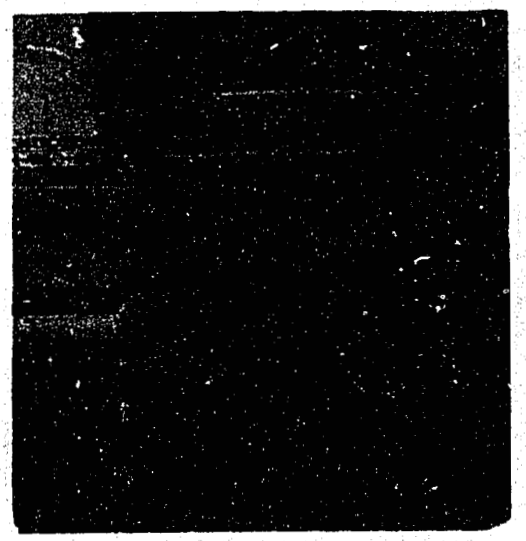
C. CONSTRICTIONS ON RIGHT AND LEFT OUTLETS (RECOMMENDED)

GLENDO DAM OUTLET WORKS

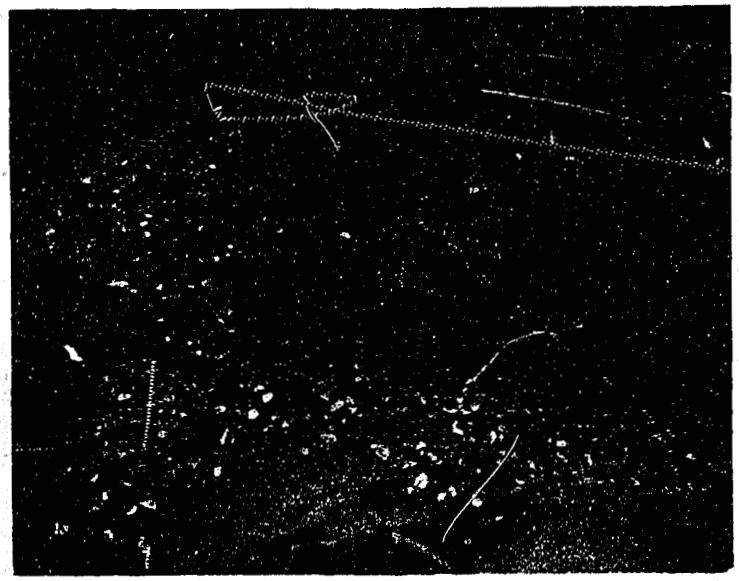
PIEZOMETRIC PRESSURES IN MANIFOLD DURING DIVERSION

1:24 SCALE MODEL





A. Constrictions on right and left outlets. Discharge = 10,000 cfs.

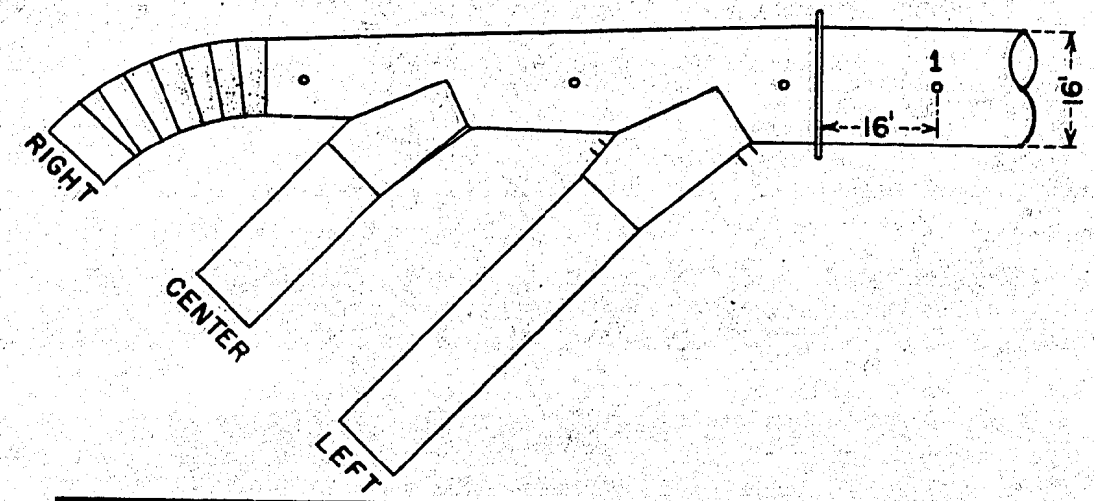


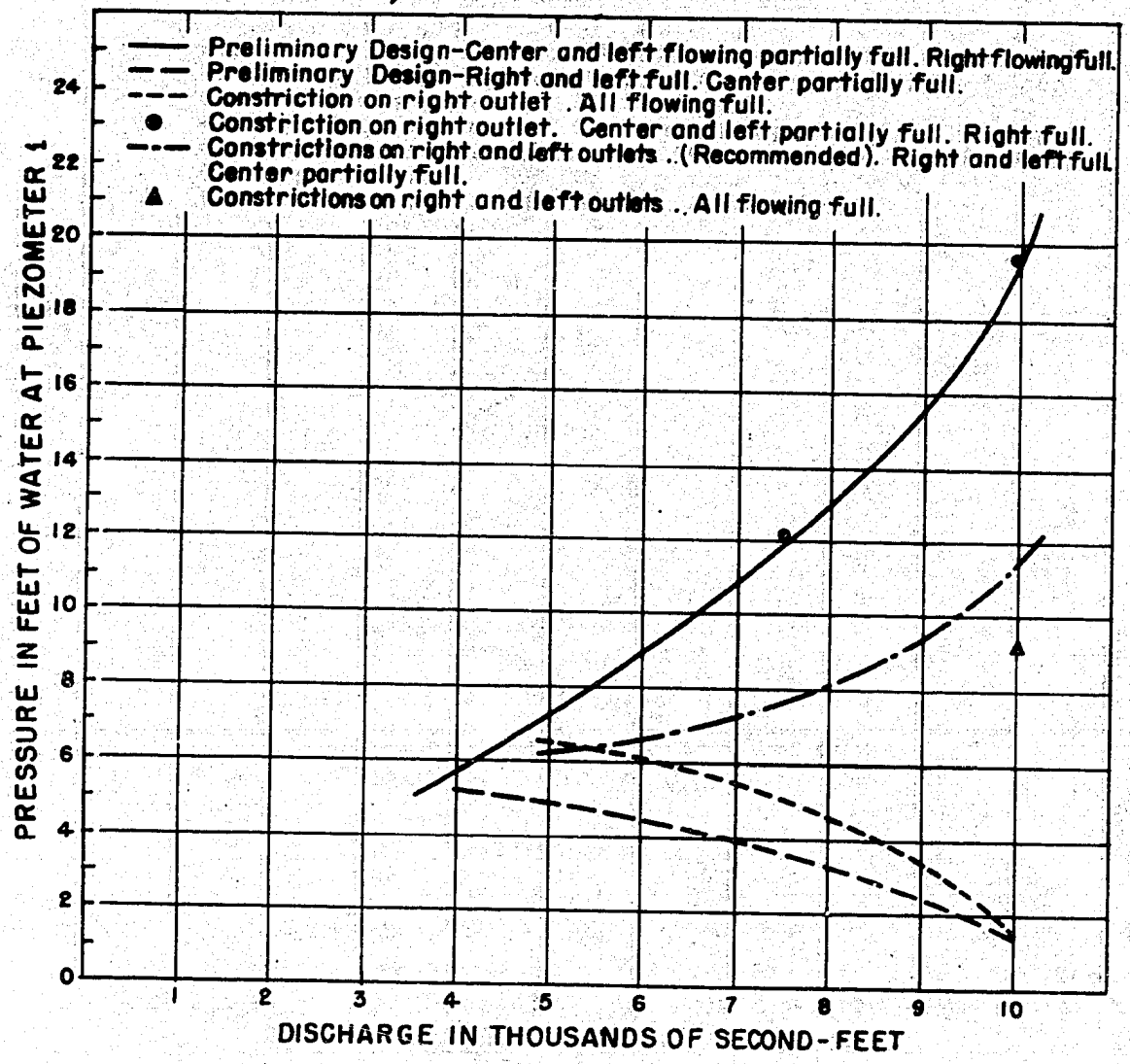
B. With no constrictions on outlets.

C. With constrictions on right and left outlet (Recommended).

Scour after Q of 10,000 for 5 hours (prototype).

GLENDO DAM OUTLET WORKS
Diversion Studies
1:24 Scale Model





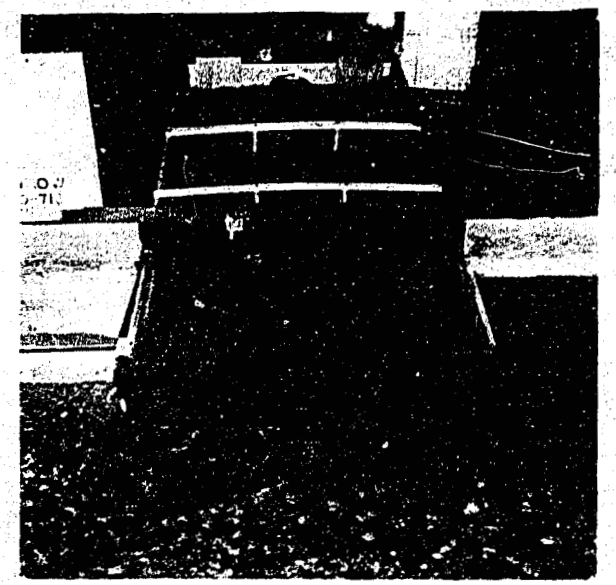
GLENDO DAM OUTLET WORKS

PRESSURE HEAD REQUIRED FOR VARIOUS DISCHARGES AND DESIGNS DURING DIVERSION

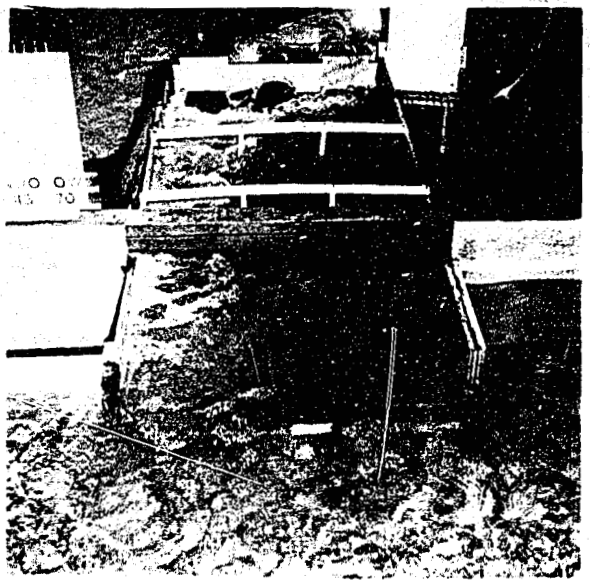
1:24 SCALE MODEL

FIGURE 28
Report Hyd-413

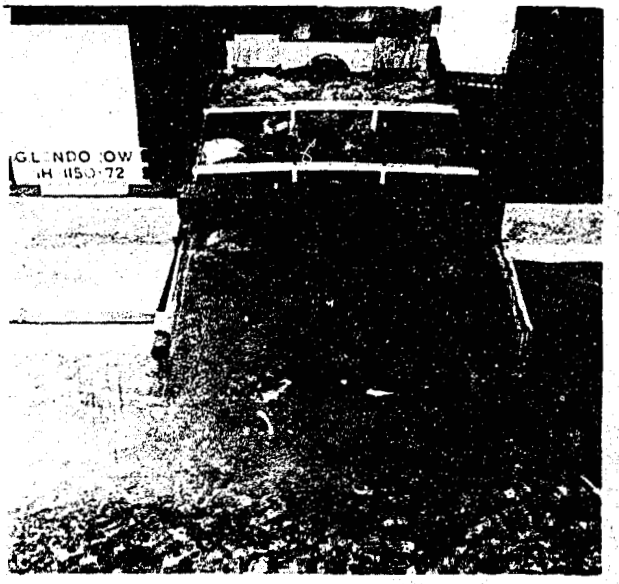
A. Q = 10,000 c.f.s. Center outlet flowing full.



B. Q = 5,000 cfs. Center outlet flowing partially full.



Center outlet flowing full.



Center outlet flowing partially full.

C. Q = 7,500 c.f.s.

GLENDO DAM OUTLET WORKS
Diversion Studies
Stilling basin performance with recommended constrictions on right and left outlets
1:24 Scale Model